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Sustainability of Urban Sprawl: Environmental-Economic Indicators for the Analysis of Mobility Impact in Italy

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Chiara M. Travisi and Roberto Camagni

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Sustainability of Urban Sprawl: Environmental-Economic Indicators for the Analysis of Mobility Impact in Italy

Summary

Sound empirical and quantitative analysis on the relationship between different patterns of urban expansion and environmental or social costs of mobility are still very rare in Europe and the few studies available provide only a qualitative discussion on this. Recently, Camagni et al. (2002) have performed an empirical analysis on the metropolitan area of Milan, aimed at establishing whether different patterns of urban expansion generate different levels of land consumption and heterogeneous impacts of urban mobility. Results confirm the expectation that higher environmental impact of mobility is associated with more extensive and sprawling urban development, more recent urbanisation processes and residential specialisation. The present paper enlarges further the empirical analysis to seven Italian metropolitan areas (namely, Bari, Florence, Naples, Padua, Perugia, Potenza and Turin) to corroborate previous results for the Italian context. The novelty of the present paper is threefold. Firstly, we are interested in exploring the changes occurred to the intensity of the mobility impact across a ten-year period, from 1981 to 1991, corresponding to the Italian economic boom years. Secondly, using an econometric analysis in cross-section, we consider several metropolitan areas at once, being therefore able to explore whether there are significant differences in the way the model explains variations in the mobility impact across various Italian urban areas. Finally, we propose a conceptual interpretation of the causal chain in the explanation of the mobility impact intensity and we test it using Causal Path Analysis.

Keywords: Urban mobility, Sprawl, Environmental sustainability, Collective costs

JEL Classification: Q56, R14, R41

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5.1 Introduction

Among recent phenomena of urban transformation in the European context, urban sprawl is one of the most debated and controversial (EC, 2004). The term *sprawl* has been coined in the North America during the second half of the 60's, when features, determinants and effects of this peculiar phenomenon of urban development and conversion captured the interest of both researchers and the governments and started to be formally analysed (e.g. Real Estate Research Corporation, 1974; Altshuler, 1977; Windsor, 1979). Although many definitions of *sprawl* has been given, a central component of most definitions -and of most tentative translations of this term¹- is the uncontrolled spreading out of a given city, and its suburbs, over more and more rural or semi-rural land at the periphery of an urban area. This involves, in the short-run, the conversion of open space into built-up, developed land and, in the medium-run, a prospective exacerbation of some detrimental environmental externalities, which typically portray cities.

Differently from traditional urban expansion, this pattern of development is not followed by an increase of the overall population of the city. Migration here is no more directed from rural toward urban areas but, instead, from the core – more densely populated - towards the periphery of urban settlements, and further². If one looks at Europe, towns and cities are expanding outwards into rural areas at a faster rate than their population is growing: a 20 percent expansion in the last 20 years with only a 6 percent increase in population over the same period (CEC, 2004). Besides, at the same time that cities are expanding outwards, many contain large amount of derelict, unused lands, and a high number of empty properties.

Another extremely significant trait of sprawl is that the process of expansion is typically disordered, unplanned, this leading to often inefficient and unsustainable urban expansion patterns. With special regard to Europe, indeed, there is a widely shared consensus on the fact that urban dispersion is, at least in part, the result of a long-lasting normative lack or, more in general, of inadequate or scarcely farsighted urban planning policies, which have not been able to interpret the direction of the '*push* and *pull*' tendencies of European towns and cities over the last twenty years (for a discussion see Camagni et al , 1998, 2002a). Of course, the factors that have assisted the success of disperse city in Europe are numerous (for a

¹ Among the others: *périurbanisation*, *ville éclatée*, *desserrement urbain*, *città diffusa*, *dispersione urbana*.

² To some extent, this is one of the motives why some commentators have defined the phenomenon of sprawl as an 'escape' from concentration and from the drawbacks of living in more compact and densely populated areas.

complete discussion see Gibelli, 1999). For what concerns residential preferences, one can enumerate: the overall worsening of the quality of life in urban areas (high cost of habitations, congestion, air pollution, noise, deterioration of public spaces, etc.); the evolution of individual preferences and taste in favour of single-household dwellings (following the US archetype); the placing out from central locations of residential in favour of service activities; the higher costs of real estate re-qualification in central areas compared to extra-urban locations; and, often, less stringent city planning and institutional constraints in the periphery. The same goes for economic activities: increase diffusion of back-office activities irrespective of accessibility economies; scarce accessibility of central areas by motorised private transport modes; increasing fiscal and administrative fragmentation are all contingent elements that have contributed to the success of sprawling patterns of urban expansions.

Today, the European Commission recognizes urban sprawl as the most urgent of the urban design issues as it leads to green space consumption, high cost of infrastructure and energy, increase social segregation and land use functional divisions, reinforce the need to travel and sharpen dependence upon private motorised transport model, leading in turn to increased traffic congestion, energy consumption and polluting emissions (OECD, 2000; CEC, 2004).

The favoured vision of high density, mixed use settlements with reuse of brownfields land and empty property, and planned expansions of urban areas rather than ad hoc urban sprawl, has been reinforced in each EC policy document on urban development starting from the “Green Paper on the Urban Environment” (CEC, 1990)³. Since that, a number of community initiatives on urban design has been implemented⁴. Nevertheless, additional efforts are needed to achieve

³ The EU Expert Group on the Urban Environment was established in 1991; the Sustainable Cities Project was launched in 1993 with the aim of promoting new ideas on sustainability in European urban settings, fostering exchange of experience, disseminating good practices on sustainability at the urban level and formulating recommendation for the EU institutions. In 1996 the EU expert Group produced a major report on “European Sustainable Cities” in support to the local Agenda 21 process. In 1997 the Communication “Towards an Urban Agenda in the European Union” (CEC, 1997) opened the efforts towards a thematic strategy on urban environment and in 1998 the Communication on “Sustainable Urban Development in the European Union: a Framework for Action” (CEC, 1998) for the first time took a real sustainable development approach with four main interdependent policy objectives: i) strengthening economic prosperity and employment in towns and cities; ii) promoting equality, social inclusion and regeneration in urban areas; iii) protecting and improving the urban environment towards local and global sustainability; iv) contributing towards good governance and local empowerment. In 2001, the EU Expert Group produced the report “Towards more sustainable urban land use: advice to the European Commission for policy and action”. On a wider level, Article 6 of the Treaty places sustainable development at the very core of the EU policies and actions, as stated in the 2001 Communication “A Sustainable Strategy for a Better World: A European Strategy for Sustainable Development” (CEC, 2001).

⁴ The European Spatial Development Perspective (ESDP, 1999), which addressed explicitly the question of how to control the physical expansion of towns and cities, has been adopted on a voluntary basis by all of the member states in 1999. After that, a number of actions has been implemented. To mention some: the European Spatial Observatory Network (ESPON) programme implements and co-ordinates research in spatial planning, putting in place a framework to collecting and analysing spatial data; the URBAN II initiative supports mixed use and environmentally friendly brown-field redevelopment, involving reduced pressures on green-field development and urban sprawl. INTERREG has offered similar opportunities. In addition, the Community supports different

widespread sustainable urban design able to fulfil such shared objectives, and concrete initiatives at national level ought to follow the current acknowledgement of the ‘dark side’ of urban sprawl. In these direction, the emphasis of the debate is on the need to ensure the adoption of a long-term strategic land use planning systems, with environmental impacts identified and minimised, able to reverse the tendency that, in the previous decade, have seen often urban development as an unplanned process leading to unsustainable expansion. The focus of the proposed solutions should be specific to the case. In fact, as each town and city is unique, it is not for this purpose to set standard system for making land use decisions, neither to define the “ideal” settlement pattern. However, the Commission is exploring the possibility of identifying guidelines on “high density” and “mixed used” new developments, the integration of green space, retrofitting urban areas to improve their sustainability, or on the continuity of the urban fabric.

Research, exchange of experience and promotion of best practice on urban land issues is therefore of particular importance and highly recommended to attain insights for policy actions. In particular, a starting point should be the identification of the actual state of sprawl-driven negative externalities in towns and cities, and their costs. Next, the identification of the cause-effects relationships that have favoured over time the phenomenon of urban sprawl should follows. We are facing in fact a phenomenon that is driven by a number of heterogeneous components – historical, cultural, social, economic, structural - which interact in the space playing different roles depending on local conditions.

The possibility to monitor the impacts generated by urban sprawl over time and space, as well as to make clearer which are its major determinants is, therefore, an important prerequisite to prepare a solid background for the definition of effective national, regional and/or local urban environment strategies. This is particularly true for Europe, compared to North America, not only because of an indisputable scientific delay of about ten-years, but also because Europe presents a very much scattered puzzle of territorial conditions, which vary from country to country, region to region and, even, city to city.

Major research challenges can be summarised as follows:

i) to qualify and quantify collective costs imputable to diffuse and scattered patterns of urban development over time and space, with the intent of drawing attention on contingent trends and tendencies, as well as on likenesses among different cities from which to share experiences;

- ii)* to achieve a comprehensive assessment of the determinants of urban sprawl with the aim of setting priority requirements and, thus, a ranking of priority management actions;
- iii)* to analyse the effects of past urban planning policies to enhance feed-back processes and the definition of good-practice for sustainable urban planning.

The focus of the present chapter is on points i) and ii), with particular emphasis on the connections among sprawl and the impacts of urban mobility. In respect to this, even though, as we said, the debate on urban development and its consequences on environmental and social issues has started to be tackled in the European spatial policy, sound empirical and quantitative results on the collective costs of sprawl are still partial. It is indeed not straightforward to measure the environmental externalities related to the phenomenon of sprawl, especially due to the difficulties of finding sound and reliable performance indicators⁵. Even more challenging is the analysis of the determinants of urban sprawl, especially if one starts from the stance that more perspicacious analyses ought to focus on a local territorial level.

Among the bunch of studies available on the European context⁶, a qualitative comparative analysis of pros and cons of different urban growth patterns by Breheny et al. (1993) presents suggestions and recommendations for urban planning actions, set at various administrative levels, but lacks relevant results on the preferable urban growth mode. Camagni et al. (2002b) performs an empirical quantitative analysis on the metropolitan area of Milan, aimed at establishing whether different patterns of urban expansion generate different level of land consumption and heterogeneous impacts of urban mobility. In particular, the study provides first insights on whether there is any significant correlation between variables describing the form of urban expansion and the impact of urban mobility, as an indicator of the pressure on the quality of day-life in metropolitan areas and on the urban environment, with the aim of providing a basis for orienting future planning policies. A mobility impact based on commuting data referring to 1991 is used to capture the level of environmental impact of mobility on commune level, estimated on the basis of trip time and modal choice. The intensity of mobility

⁵ At a local level, the European Commission has recently provided a set of urban environmental indicators, useful to provide focus for establishing initial policy and action plans, as well as for communicating locally to citizens and to raise the general level of awareness on key urban environmental indicators, which can be used on a voluntary basis (European Common Indicators, ECI www.sustainable-cities.org/indicators/index.htm). Although this includes interesting parameters –such as local mobility and passenger transportation, or the availability of local public open areas and services - the level of detail employed is nevertheless insufficient to cover extensively all of the issues related to sprawl.

⁶ It is not the purpose of this paper to provide an extensive analysis of the North America experience, which expresses incomparable administrative, institutional, territorial and suburbanization features in respect to the European scenery. Nevertheless, it worth to notice that the great majority of empirical studies on the collective costs of mobility nowadays available relate mostly to North America. Yet, results show a significant correlation between different forms of urban development and collective costs, which appear to be higher for less dense.

impact is then explained by some variables controlling for geographical, socio-economic, morphology and transport efficiency factors. The results of the analysis confirm the expectation that a higher environmental impact of mobility is associated with more extensive and sprawling urban development, more recent urbanisation processes and residential specialisation. The same procedure is used in two subsequent studies on the urban areas of Brescia (Camagni et al. 2002) and Bologna (Musolino and Guerzoni, 2003), both referring to the year 1991.

More recently, Salatino (2004) follows the methodology by Ewing et al. (2002) and provides a static analysis, for the Italian regions, of the univariate correlation between an aggregate indicator of spatial dispersion and a number of parameters that capture some costs imputable to sprawl, with special focus on the private costs of mobility (e.g.: household petrol consumption, household transport expenditures, and so forth). Salatino (2005) proposes a similar static analysis at national level for 11 EU countries, including Italy, and a Path Analysis exercise to find causal relationships among the variables analysed. Both analyses show positive and significant correlation among parameters controlling for urban dispersion and transport costs, overall providing further indications of the fact that more dense urban forms are accompanied with higher costs of mobility.

In the analysis proposed in the present Chapter, a local level focus is adopted and an empirical quantitative procedure similar to the one employed by Camagni et al. (2002b) is enlarged to other seven Italian urban areas, namely: Bari, Florence, Naples, Padua, Perugia, Potenza and Turin⁷.

In respect to the previous papers, the novelty of the present study is threefold. Firstly, the analysis is dynamic and explores the changes occurred to the intensity of the mobility impact across a ten year period, from 1981 to 1991. This is a relevant decade to focus on with the intent to study the Italian context for a number of reasons: it corresponded to an overall 'deregulation' period that is thought to have promoted, indirectly, an unprecedented success of diffuse urban development patterns; it corresponded to an important economic boom, which led to new practice of private mobility.

Secondly, using multivariate cross-section regression analyses, we consider several urban areas at once, being therefore able to explore whether there are significant differences in the way the model explains variations in the mobility impact across various "prototypes" of Italian urban areas. Cities are selected, in fact, to provide a representative picture of metropolitan and polycentric Italian urban agglomerations, either located in the North, Centre or South of Italy (see Figure 1).

⁷ Each urban area is a province (from the administrative point of view), and it includes in its territorial borders a number of communes. Overall, more than 700 communes are analysed (see Figure 1).

The paper tries, on one hand, to find empirical evidence of the increasing collective impact of urban mobility and, on the other hand, to figure out whether factors expected to influence the intensity of mobility impact do vary as the city of concern varies or, instead, if results are valid and sound for all the Italian cities analysed. This is a very important point for future research, which can help to give an indication on which ought to be the level of analysis to be preferred for studying the negative effects of urban sprawl on mobility, and their rousing factors. Available studies, in fact, propose either national, regional or local level analyses, often disregarding whether the impacts of sprawl are actually traceable and measurable at higher levels than the local one. In particular, the urban scale to which empirical analyses and case studies should apply remain uncertain.

Finally, we propose a conceptual interpretation of the causal chain in the explanation of the mobility impact intensity and we test it using Causal Path Analysis (CPA) (see a previous version of this study in Travisi and Camagni, 2004). Differently from Salatino (2005), which uses path analysis as an exploratory tool through which to highlight, with an inductive process, incidental correlations among variables, path analysis here is used to test an *a priori* defined conceptual causal model on the impacts of mobility.

The reminding of the paper is organized as follows. In Section 2 we present the conceptual underpinnings of the development of the mobility impact model and describe our hypotheses as to the reasons for heterogeneities in the intensity of mobility across cities. In Section 3 we present results of the dynamic analysis of the intensity of the mobility impact across 1981-1991; while Section 4 presents and discusses the main findings of our empirical multivariate cross-section regression analyses. In Section 5 a conceptual interpretation of the causal chain in explaining the impact of mobility is proposed and empirically tested. Finally, Section 6 provides conclusions and recommendations for future research.

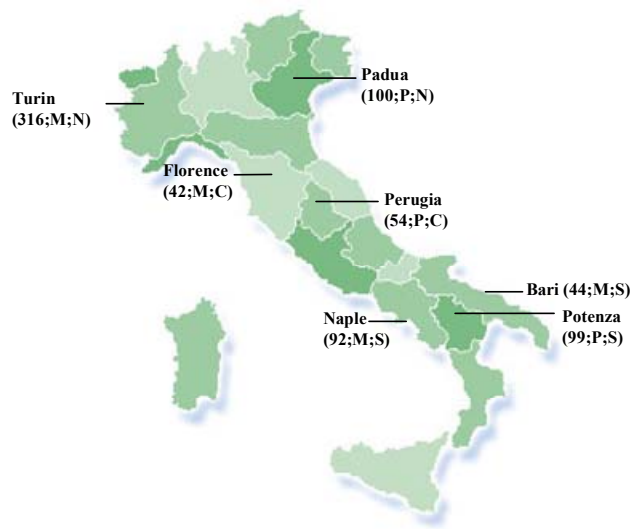


Figure 1: Geographical location and a taxonomy of the urban areas of concern. In brackets is reported: the number of communes in each area, the type of urban settlement (M: Metropolitan; P: Polycentric) and their geographical location (N: North; C: Centre; S: South). Note that polycentrism is measured as the ratio between the population of the chief town of a given urban area (province) and the sum of the population of the ten biggest cities belonging to the province. A given urban area is defined as Metropolitan and Polycentric, respectively, whenever this ratio is bigger or lower than 0.5.

2.1 Explaining the impact of mobility in Italy

2.1.1 Creating a mobility impact index

Many studies on urban sustainability show that the demand for mobility is an important component of the environmental impact of urban growth but, so far, empirical evidences and a systematic quantification of the intensity of this phenomenon are still lacking in the European context and still partial at the Italian level. The first research question addressed in this paper is, therefore, to measure the intensity of urban mobility at local level, for a group of seven Italian urban areas representative of metropolitan and polycentric urban agglomeration either located in the North, Centre or South of Italy. Previous results by Camagni et al. (2002a, 2002b) Musolino and Guerzoni (2003), Salatino (2004) show, for the Italian context, that urban settlements characterised by sprawling patterns of development are associated with a higher demand of urban mobility and higher environmental impacts than more compact ones.

An additional question concerns the dynamic of the demand of urban mobility and the related collective costs for the Italian context. In particular, as we move from 1981 to 1991 commuting data, we expect to observe an overall increase in the intensity of the impact of urban mobility, caused by the progressive replacement of diffuse in place of

more dense urban development patterns, and by a change in individual preferences for alternative transport modes towards private mobility.

How to capture urban mobility? For Italy, the lack of reliable mobility data entails a methodological and operational problem. As far as mobility is concerned, we use the only reliable data available at the local (commune) level, i.e., the journey-to-work data recorded in the 1981 and 1991 Census for each active resident. These are disaggregated by mode into 6 categories⁸ and, within each mode, by the time taken: up to 30, 31-60, over 60 minutes.

As trip length is not recorded in the Census, a drawback of this approach is that it is not possible to link trip duration and length and, therefore, it is not possible to distinguish between the effect of distance and the effect of vehicle speed and traffic conditions. Another limitation concern the nature of available data, which account only for one segment of urban mobility (commuting), disregarding all the non-systematic aspects of mobility. Being aware of the existing data limits, we employ –as in Camagni et al. (2002b)– journey-to-work data to develop a so called *mobility impact index*.

From the data on travel modes and the time length of commuter trips (direction outside or within each municipality), an indicator of the environmental cost of mobility is created. As the environmental pressure of mobility is strictly related to mode and time length, a weighted index of pressure is therefore defined for 18 different combinations of mode and time, according to the structure of available data.

The matrix of weights for time and mode, applied to each commuting trip to capture its level of environmental pressure is described in Table 1, and it is based on two main assumptions:

- For any given mode, the impact of a trip per unit of time decreases with the trip length, according to a number of simple, but not trivial, evidences: gas emissions and pollution generated by vehicles are higher at the beginning of the trip; traffic fluidity increases outside urban areas; trains stops decrease on longer journeys, etc.
- Set conventionally at 1.00 per passenger per minute the weight of the trip by car, the weight of the various modes for a given duration is, respectively: 1/3 for motorcycle and bus; 1/5 for rail trips and transported passengers; zero for pedestrians or bicycle trips and passengers (this is justified by considering that the possible lengthening of a journey due to the presence of the passenger is already absorbed by the length of the journey travelled by the driver).

Using the values in Table 1, the commuters recorded in the Census are transformed into ‘Equivalent Impact Commuters’ (EIC). Given the municipality k th, the intensity of the mobility impact, I_k , can be estimated as the ratio between the EIC and the actual commuters (at commune level) as follows:

⁸ The categories considered are: walking or other soft means; car driver; motorcycle; car passenger; train, tram or metro.

$$I_k = \frac{\sum_{ij} m_{ij} w_{ij}}{\sum_{ij} m_{ij}} \quad \text{Eq- 1}$$

where: m_{ij} is the number of commuters moving within the k th municipality plus the number of commuters going outside the k th municipality for the i th travel mode and the j th trip time class; and w_{ij} is the weight assigned to the i th travel mode and the j th trip time class (see Table 1).

A drawback of this approach relates to the definition of the weight matrix that, as it is now, it is not linked to any physical impact dimension and, thus, provides a relative rather than an absolute measurement of the urban mobility impact. On the other hand, a big advantage of this methodology compared to others more direct indicators of environmental impacts is that it refers directly to the demand of urban mobility generated in each municipality as a consequence of its settlement pattern, rather than referring to some other mobility effects, which can often originate from other municipalities⁹.

The subsequent sections discuss the dynamic of the mobility impact index in the Italian context during the decade 1981-1991, and provide a multivariate analysis of factors explaining the intensity of mobility impact across Italy, relating 1991.

Table 1: Weights by travel time and travel mode.

	<i>Classes of travel modes</i> (i th)	Weights for modes	Time (min)		
			<i>0-30 min</i>	<i>31-60 min</i>	<i>>60 min</i>
<i>Classes of trip time</i> (j th)					
Average trip time			15 min	45 min	75 min
Weight per time unit			1.20	1.00	0.80
Equivalent trip time			18 min	45 min	60 min
Travel mode	<i>Walking or other soft means</i>	0.00	0.00	0.00	0.00
	<i>Bus</i>	0.33	0.13	0.33	0.44
	<i>Private car (driver)</i>	1.00	0.40	1.00	1.33
	<i>Motorcycle</i>	0.33	0.13	0.33	0.44
	<i>Private car (passenger)</i>	0.00	0.00	0.00	0.00
	<i>Train, tram, underground</i>	0.20	0.20	0.20	0.27

⁹ To improve the methodology, we are now trying to re-define the weight matrix on the basis of gas emission factors related to travel mean and trip time.

2.1.2 Dynamic of mobility impact during 1981-1991

Before exploring the determinants of the intensity of mobility, we analyze the distribution of the mobility impact index across the seven urban areas (province) of concern and its variation during the period from 1981 to 1991. As we said, during this decade Italy experienced the so called ‘deregulation’ period and an intense economic growth, two factors that have certainly significantly contributed to the diffusion of sprawl in this country, traditionally scattered by densely populated and well-structured cities. It is therefore interesting to follow the dynamic of the demand of urban mobility during such period, in consideration of this process of development and modernization, and the consequent increase in income level and change in mobility individual habits and behaviours.

This analysis is here performed at different levels, so that we look at: i) the average impact within each province; ii) the average impact of the main city within each province (i.e. the chief town); iii) the average impact related to minor towns located within each province. This allows to take into account the fact that, within a given province, the dynamics of both socio-economic and territorial conditions during the period 1981-1991 can be significantly different if we consider main or minor towns.

Figure 2 and Figure 3 show, respectively, the distribution of mobility impact and box-plots reporting median, percentiles and minimum and maximum values for subgroups (based on province, geographical location and level of polycentricism) for 1981 and 1991. Table 2 provides descriptive statistics of the mobility impact index for 1981 and 1991 at the province level, whereas Table 3 shows the average values and the percentage rate of increase of the impact for provinces, chief towns and minor towns.

If we look at absolute values in Table 2, a first result is that the impact of urban mobility decreases as one moves from northern to southern Italian regions, as one would expect given the higher income level of northern Italian area, which normally favours the diffusion of motorised private travel means. The higher impact values refers to Turin, and this is not surprising as this is the ‘land’ of the main Italian car producer, Fiat. Nevertheless, the positive trend in the intensity of the mobility impact over the decade 1981-91 characterises all the urban settlements considered, and it is higher for those areas located in the southern Italian regions, Bari and Potenza. The increment ranges from a minimum of 14.8 percent for Turin, to a maximum of the 37.3 percent for Potenza (Table 3). Interestingly, with the exception of Turin and Padua, minor towns experienced an higher percentage increase in the impact of mobility than chief cities.

A second result is, therefore, that urban mobility has increased noticeably across the whole Italian peninsula for reasons that are beyond the increase of the Italian population, which on average has not exceeded the 5.3 percent points. A thorough analysis of the reasons for such an increase lies outside the scientific aim of this paper

and would require an investigation on how the socio-economic features of a given urban settlement has varied during this time lag (e.g. household income, transport networks and infrastructures, changes in production factors and job markets, etc.). Without entering into the detail of this discussion, it suffices to say that among the main drivers of such tendency the literature indicates, for Italy, the increasing demand of urban mobility, together with a shift of individual preferences towards private mobility motivated, to some extent, by the higher income level that made car market accessible to wider portions of citizens, as well as by the lower competitiveness of public compared to private travel means (Giordano et al., 2001; Lattarulo, 2003). The change in individual preferences towards private travel mode is confirmed by the results showed in Table 4. Table 4 indicates that, during the decade 1981-1991, the distribution of commuters by travel modes has changed in favour of private travel means, with a particularly relevant increase in the use of private car. Such increment ranges from a minimum of 9 percent for Naples, to a maximum of 14 percent for Turin and Padua. At the same time, other private soft means have been abandoned and the incidence of the use of public transport has also decreased, especially for what concerns the use of public bus. As the weight matrix use to compute the mobility impact index assigns higher impacts to private transport means (especially car), we observe higher impact values for 1991¹⁰.

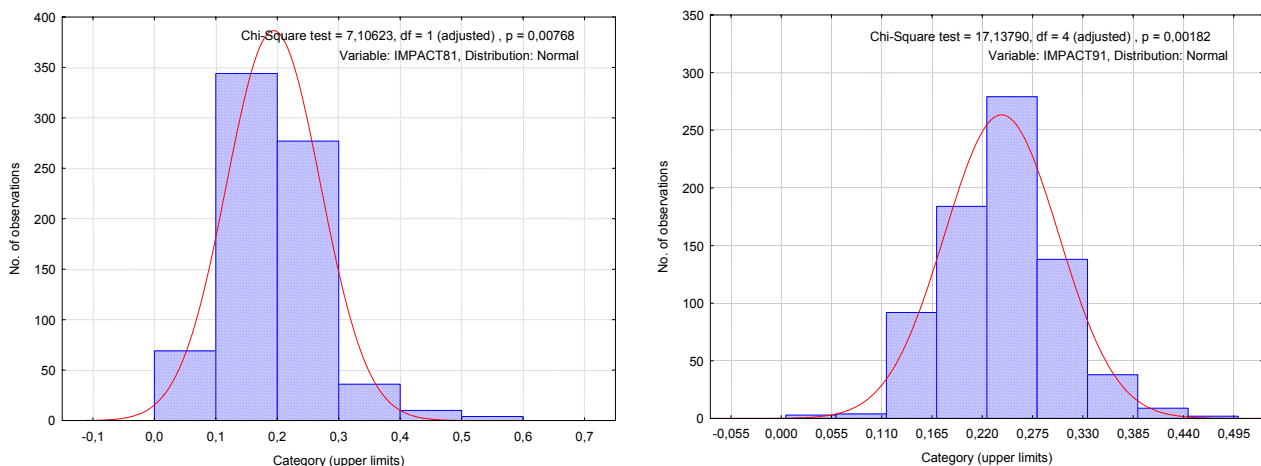


Figure 2: Distribution of mobility impact index for 1981 and 1991.

¹⁰ This paper does not investigate the reasons why individual preferences for alternative travel modes has changed.

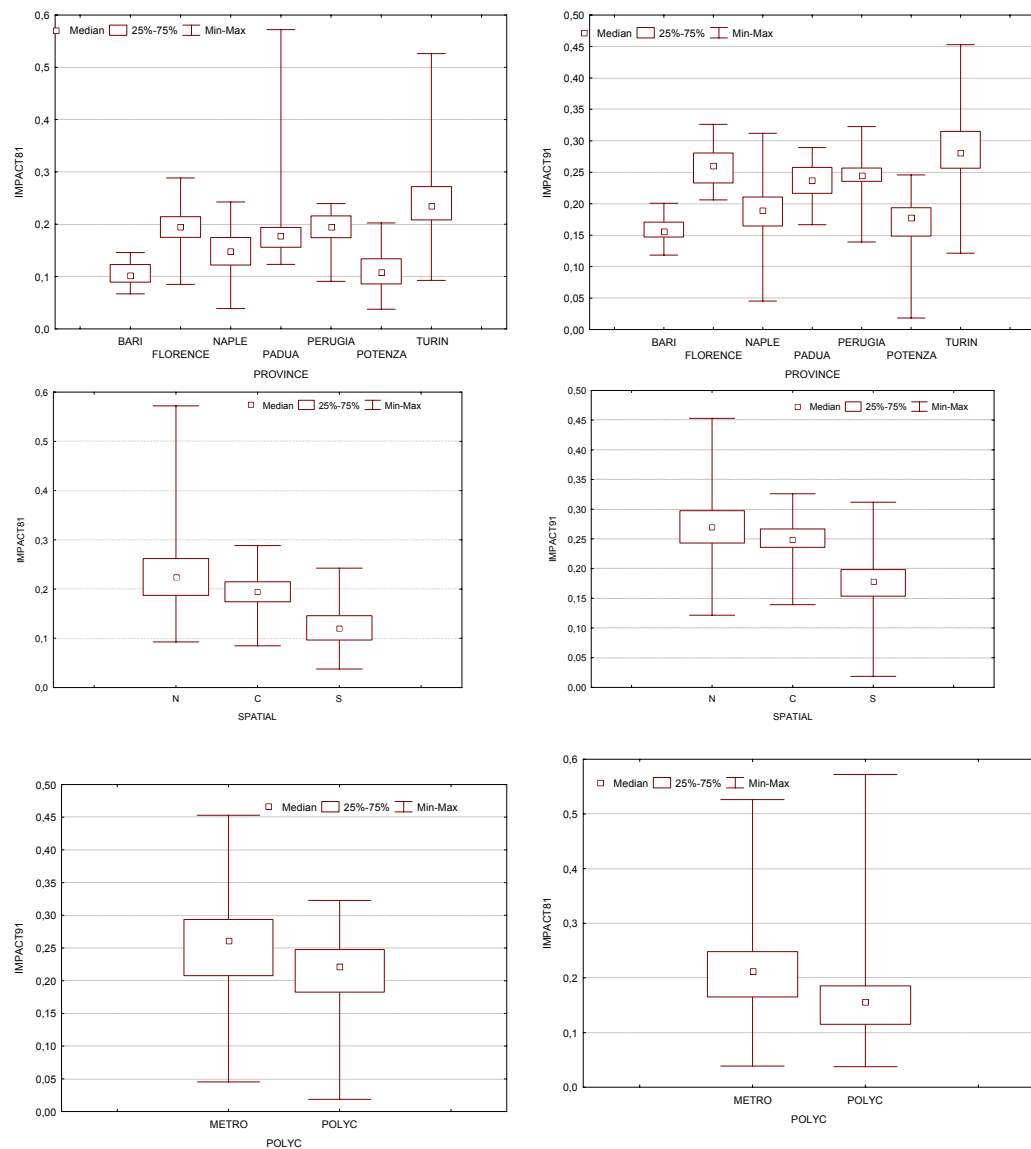


Figure 3: Box-plots reporting median, percentiles, minimum and maximum values of the mobility impact index for 1981 and 1991, according to the province, their geographical location and their level of polycentrism.

Table 2: Descriptive statistics of mobility impact index for 1981 and 1991.

<i>Variable</i>	<i>Nobs</i>	<i>Mean</i>	<i>Median</i>	<i>Minimum</i>	<i>Maximum</i>	<i>Std. dev</i>
IMPACT81						
Bari	44	0,105	0,102	0,067	0,146	0,021
Florence	42	0,195	0,194	0,085	0,288	0,037
Naples	91	0,151	0,149	0,039	0,242	0,043
Padua	100	0,198	0,178	0,123	0,572	0,089
Perugia	48	0,189	0,195	0,091	0,240	0,032
Potenza	99	0,109	0,108	0,038	0,202	0,032
Turin	315	0,245	0,235	0,093	0,526	0,059
IMPACT91						
Bari	44	0,159	0,156	0,119	0,201	0,019
Florence	42	0,260	0,261	0,206	0,326	0,028
Naples	91	0,189	0,190	0,045	0,312	0,042
Padua	100	0,237	0,238	0,167	0,289	0,028
Perugia	48	0,244	0,245	0,139	0,323	0,030
Potenza	99	0,174	0,178	0,019	0,246	0,036
Turin	315	0,287	0,282	0,121	0,453	0,049

Table 3: Mean value and rate of increase of the mobility impact index per urban area and time period.

	1981			1991			Increase rate 1981-91 (%)		
	(a) Province	(b) Chief town	(c) Other	(a) Province	(b) Chief town	(c) Other	(a)	(b)	(c)
Bari	0,105	0,142	0,115	0,159	0,181	0,155	33,9	21,9	26,0
Florence	0,195	0,184	0,195	0,260	0,206	0,262	25,2	10,8	25,5
Naple	0,151	0,195	0,150	0,189	0,203	0,189	20,4	3,9	20,6
Padua	0,198	0,174	0,198	0,237	0,221	0,237	16,3	21,3	16,3
Perugia	0,189	0,199	0,189	0,244	0,240	0,244	22,7	17,0	22,6
Potenza	0,109	0,148	0,109	0,174	0,199	0,174	37,3	25,7	37,5
Turin	0,245	0,192	0,245	0,287	0,241	0,287	14,8	20,2	14,8

Notes:

(a) mean impact value for each urban area (province)

(b) impact value for the chief town of a given province

(c) mean impact value referring to the minor towns of a given province

Table 4: Percent distribution of commuters by travel mean during 1981 and 1991.

		Naples	Turin	Bari	Florence	Padua	Perugia	Potenza
<i>Walking or other soft means</i>	<i>1981</i>	44%	29%	56%	30%	37%	28%	58%
	<i>1991</i>	41%	22%	45%	23%	26%	21%	41%
<i>Bus</i>	<i>1981</i>	24%	25%	13%	23%	17%	24%	17%
	<i>1991</i>	17%	18%	10%	15%	15%	17%	19%
<i>Private car (driver)</i>	<i>1981</i>	15%	28%	17%	27%	25%	32%	16%
	<i>1991</i>	24%	42%	28%	37%	39%	45%	29%
<i>Motorcycle</i>	<i>1981</i>	1%	2%	2%	8%	12%	6%	1%
	<i>1991</i>	2%	1%	2%	11%	7%	3%	1%
<i>Private car (passenger)</i>	<i>1981</i>	4%	7%	6%	6%	7%	7%	6%
	<i>1991</i>	7%	9%	10%	8%	10%	11%	9%
<i>Train, tram, metro</i>	<i>1981</i>	11%	10%	6%	6%	2%	3%	3%
	<i>1991</i>	10%	8%	6%	6%	3%	2%	2%

2.1.3 Determinants of mobility impact: an exploratory univariate analysis

The hypothesis underpinning this paper is that, within a relatively homogeneous area (in terms of income level and main socio-economic conditions), such as each of the seven Italian urban areas of concern here, the local differences in the mobility patterns can be explained, at least to a certain extent, by the typology of urban development occurred in such areas. Thus, the form in which urban growth has occurred and, as well, its dynamic is expected to influence the intensity of the mobility impact at a local level and its spatial distribution. In particular, the economic literature on this issue suggests that a number of factors might have a role in explaining why urban mobility changes its intensity across various countries and urban areas. In particular, we expect that four types of variables might influence the intensity of mobility impact at a local level: geographical, socio-economic, morphology variables, and variables measuring the accessibility and efficiency of private versus public transport.

The spatial distribution of the indices of impact intensity is examined using an econometric analysis to ascertain whether there are significant correlation with any of the selected independent variables describing the characteristics of a given urban settlement. All regression variants refer to 1991 and the mobility impact index is used as the dependent variable and captures, at commune level, the intensity of the collective impacts associated with the demand of urban mobility. Few variables controlling for structural and socio-economic differences across urban areas are used as explanatory variables. The relationship is established using least squares estimators. Three classes of explanatory variables are included in the econometric analysis: i) spatial, ii) structural socio-economic, and iii) variables relating to the demand and supply of urban mobility.

Spatial variables include factors that contribute to describe the structural and spatial configuration of a given municipality located within a certain urban area. Among the number of possible parameters, indicators and proxies that can be used to capture the spatial structure of a given towns, we consider a variable that accounts for the distance of a given municipality from the chief town of the urban area to which it belongs (DISTANCE), a variable estimating the incidence of rural landscape within a given municipality (RURAL), and the overall city dimension (POPTOT). In order to describe urban areas according to their sprawling behaviour, we use -as a proxy- the gross density of the urban settlement (DENSITY). Among the socio-economic variables we consider the dynamic of urban growth in the decade under analysis (GROWTH), and a variable explaining the 'functional mix' a given municipality (MIXITE). Finally, the third class of factors includes three variables, which control, respectively, for the accessibility and efficiency of public transport in a given municipality, and for its self-containment capacity (SHAREPUB, COMPUB, SELFCONT). Detailed description and descriptive statistics of explanatory variables are provided in Table 5 and Table 6.

In respect to the abovementioned discussion, our main expectations can be summarised briefly as follows. Population density is expected to have mainly an indirect negative effect on the mobility impact, through its influence on the average trip time of public transport and, hence, on the modal split of commuter trips in favour of public transport¹¹. For what concerns the city dimension, we expect to notice an overall increase in the intensity of mobility moving from smaller to bigger towns, due to the fact that the number of motorised vehicles circulating increases, as well as trip time, and this favours traffic intensity and congestion. Nevertheless, the effect of city dimension might be compensated by the travel modal choice, whether oriented towards more environmental friendly and public ones, and also by the city density, whether high.

Demographic growth rate is expected to show a positive relationship with the intensity of mobility impact. The impact index is expected to increase with the urban dynamics of the commune of concern: in fact, a high population growth rate is generally also associated with the existence of areas of recent expansion, typically scattered all around the older urban conurbation. The literature also gives considerable importance to the residential *versus* productive attitude of a municipality, in connection with the demand of mobility as well as with sprawl. Sprawl is in fact both a cause and an effect of land use functional divisions, which reinforces the need to commute and increases dependence on private transport modes. This relationship can be conveniently interpreted as an indicator of the level of functional diversification-integration-segregation, i.e. sort of a ‘functional mix’ of each municipality. In particular, we expect to find a negative relationship with the mobility impact indicating that urban mobility becomes more intense as the proportion of employment decreases whereas the residential vocation of the area increases. The relationship between the impact of urban mobility and the efficiency and competitiveness of public transport is also relevant. In respect to this, Camagni et al. (2002b) find empirical evidence that, at least for the metropolitan area of Milan, the mobility impact index is inversely correlated to the share and competitiveness of public transport. Another potentially relevant source of variation concerns the direction of commuters during home-to-work daily trips. In this case, we focus on whether commuters move within the city borders, or whether they are directed outside their own residential town, in connection with the “functional mix” variable. Therefore, we experiment whether what we indicate as the “self containment” capacity of a given town can help to explain variations in the intensity of the mobility impact. As the literature does not suggest which direction one should expect, our analysis will provide original insights on this concern.

We analyse first univariate relationships between dependent and independent variables using pooled and categorised data, after proceeding with the normality test of the independent variables. Figure 4a provides scatter plots, which give preliminary

¹¹ We are aware though that, over a certain level and under specific local conditions, high urbanisation density can contribute to the phenomenon of congestion and increase the overall impact of mobility. Nevertheless, the present paper is not addressing this issue.

information on the direction of each univariate relationship. Figure 4a shows that spatial factors (i.e. RURAL, DENSITY, DISTANCE, POPTOT) are all negatively correlated with the impact of mobility, and that such correlations are statistically significant. Differently, the city dimension (POPTOT) deserves a thorough discussion. The related scatter plot shows that the mobility intensity decreases as the city dimension rises. This contradicts our expectation to find a positive and significant univariate relationship between these variables but, on the other hand, the scatter plot between city density and its dimension shows that, on average in our sample, bigger cities are also those more densely built and therefore, in principle, less affected by sprawl.

Middle graphs refer to socio-economic factors (Figure 4b). As expected, GROWTH is positively correlated with IMPACT; while, in contrast with our expectations, the relationship with the log of MIXITE is also positive. Nevertheless, if one draws scatter plots categorised on the basis of the spatial position of the urban areas (i.e., located in the north, centre or south of Italy), one can observe negative and significant correlations between the impact of mobility and the functional mix variable.

Bottom graphs refer to the relationship between the intensity of mobility impact SELFCONT, SHAREPUB and COMPUB and show, in all of the cases, a negative and significant correlation (Figure 4c) with the impact of mobility. If one moves to categorical scatter-plots though, the direction of these relationships changes according to the geographical position of cities and towns, and this will need to be address in the regression analyses.

In sum, the exploratory univariate analysis of the factors determining the impact of urban mobility indicates that our a priori expectations are generally confirmed. Interestingly, some of the univariate relationships that are difficult to capture using pooled data (for instance, the functional mix variable), emerge clearly once we use sub-samples based on the spatial position of urban areas, this suggesting that simple univariate correlations can hardly be captured at national level, or that they might lead to misleading results (see Salatino, 2005). In the reminder of the paper, we move from univariate to multivariate relationships and provide results of different variants of cross-section regression analysis, all referring to 1991.

Table 5: Variables list and description.

<i>Type of variable</i>	<i>Abbreviation</i>	<i>Definition</i>
Dependent:	IMPACT91	Average intensity of the impact of urban mobility at commune level. The impact of mobility is calculated as the ratio between the EIC and the number of commuters recorded in the Census
Spatial	DISTANCE	Distance [Km] between the centroid of a commune and the centroid of the capital of the province
	RURAL	The incidence of rural areas is calculated as the rural area [Km ²] over the total land area [Km ²]
	DENSITY	Gross density of the commune, calculated as the number of residents over the whole land area [Km ²]
	POPTOT	Total number of residents
	SUPTOT	Total land area [Km ²]
	NORTH	Takes value 1 if the city is located in the North of Italy
	CENTRE	Takes value 1 if the city is located in the Centre of Italy
	SOUTH	Takes value 1 if the city is located in the South of Italy
Structural	MIXITE	Ratio between the number of employments and residents of a commune
	GROWTH	Growth rate of the population between 1981 and 1991
	METRO	Takes value 1 if the urban area is metropolitan
	POLYC	Takes value 1 if the urban area is polycentric
Mobility	COMPUB	Relative competitiveness of public transport, calculated as the ratio between the average time taken for trips made with private transport and the average time taken for trips made with public vehicles (the ratio is multiplied for 100 for computational reasons).
	SHAREPUB	Market share of public transport calculated as the percentage of all trips made by public transport
	SELFCONT	The degree of containment of urban mobility within a given urban settlement (at commune level), measured as the ratio between the number of commuters moving out of the commune, and the number of commuters moving within and going outside the commune

Table 6: Descriptive statistics of independent variables, referring to 1991.

<i>Variable</i>	<i>Mean</i>	<i>Minimum</i>	<i>Maximum</i>	<i>Std.dev</i>
DISTANCE	71,78	1,00	157,00	30,91
DENSITY	5,10	0,46	9,48	1,56
RURAL	48,99	1,77	175,15	24,23
GROWTH	2,25	55,30	69,90	10,34
MIXITE	0,48	-	2,34	0,29
SELFCONT	0,36	0,01	1,00	0,16
COMPUB	35,21	3,71	174,57	18,65

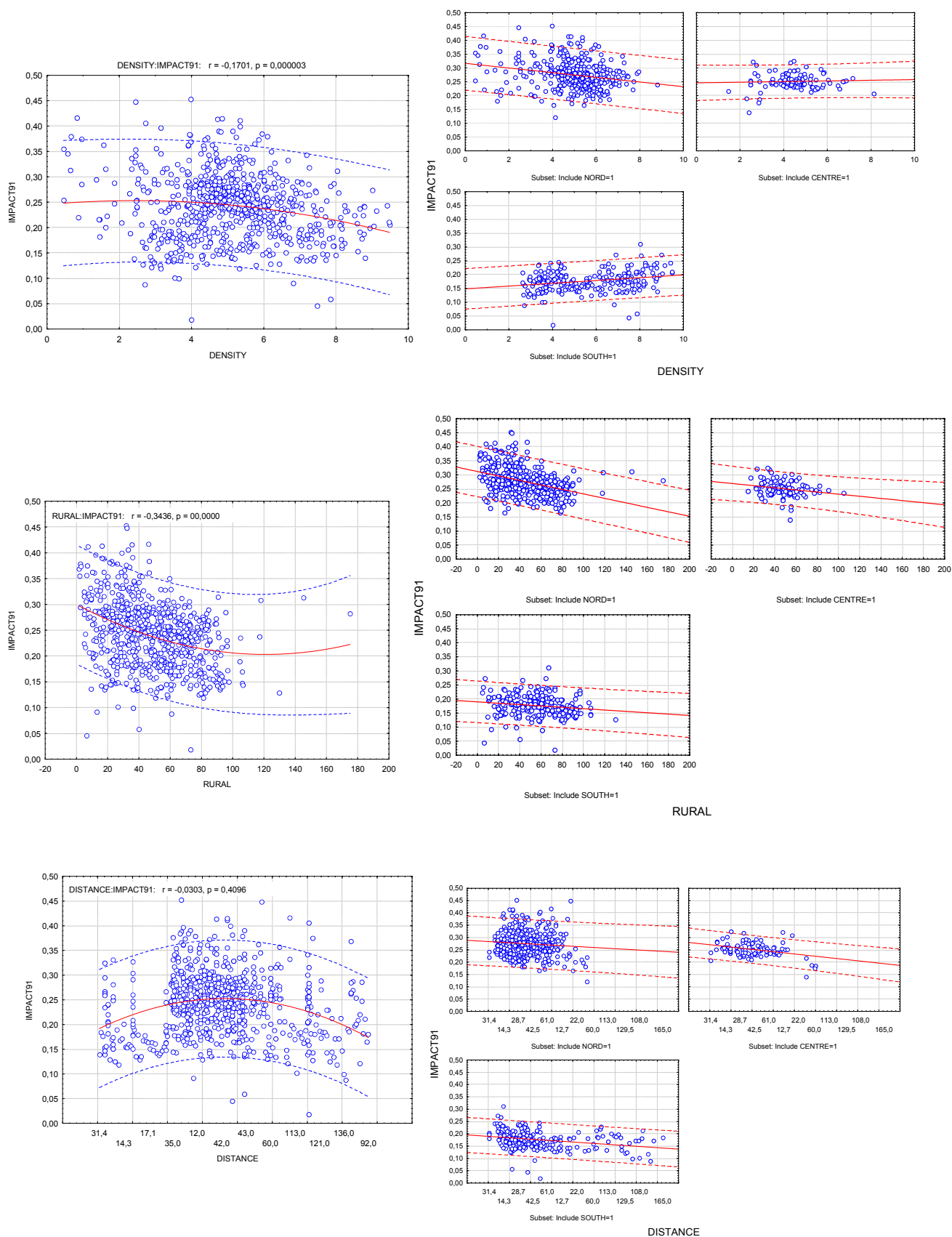
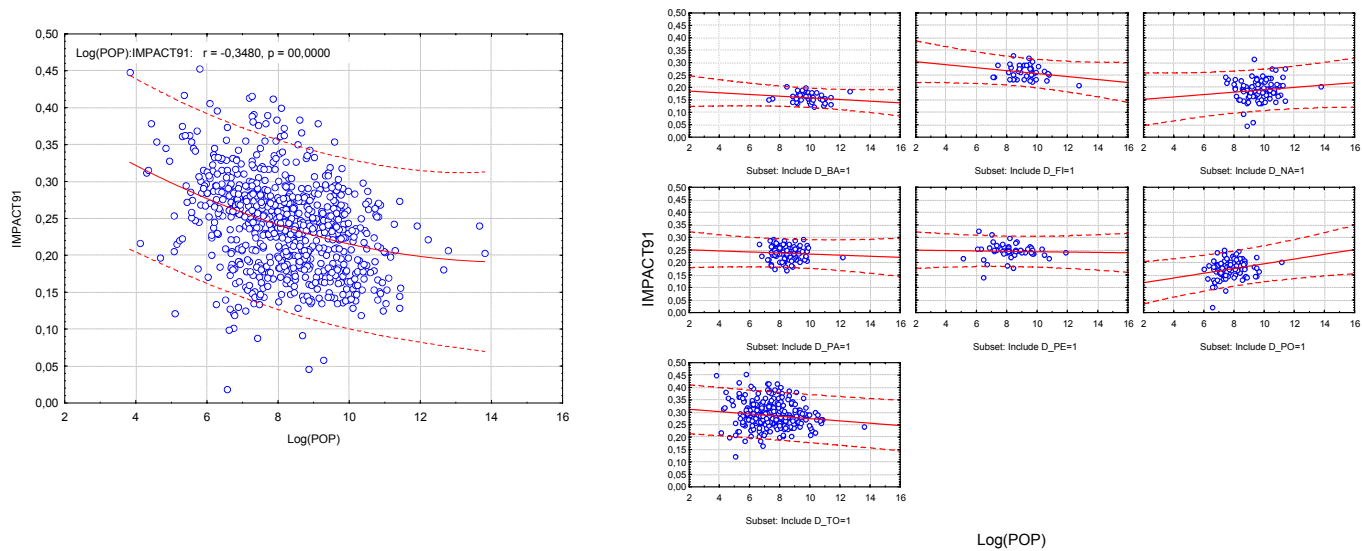
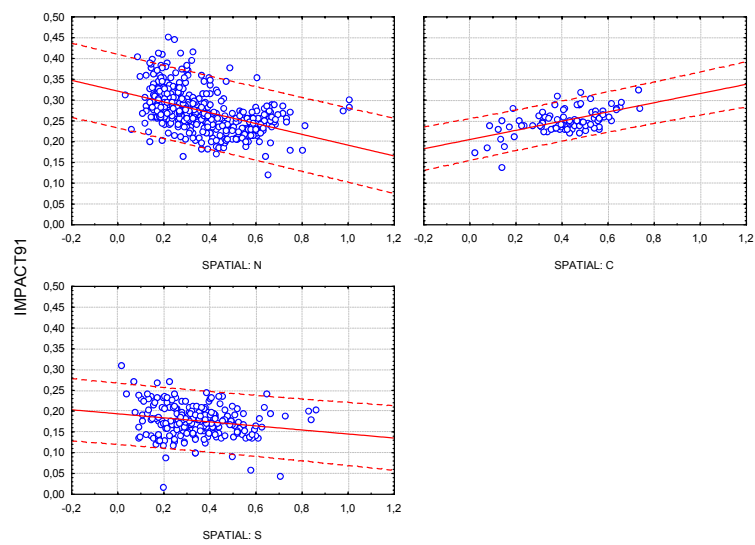
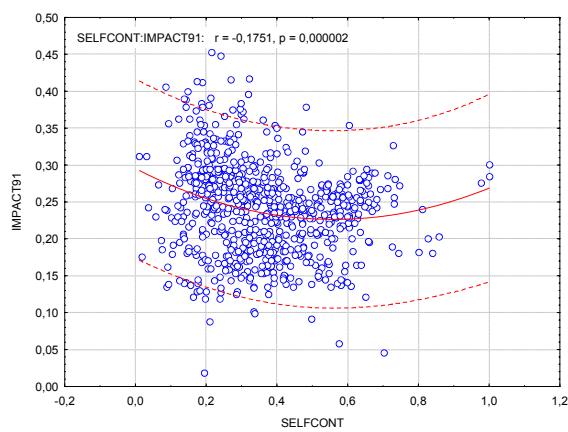
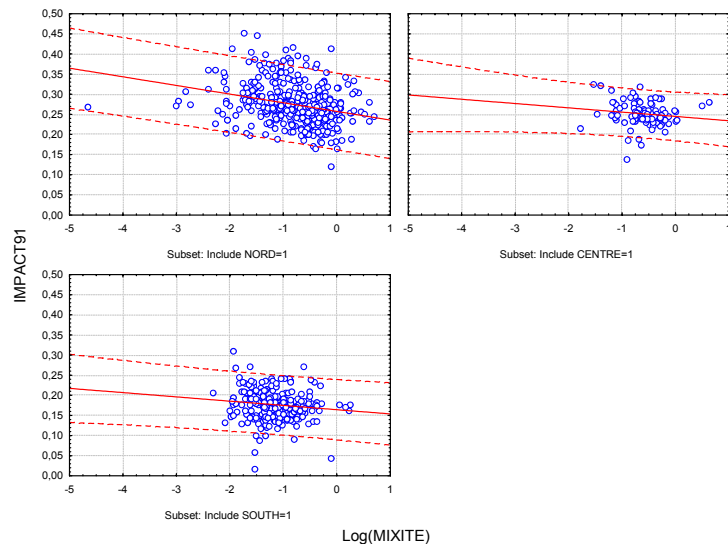
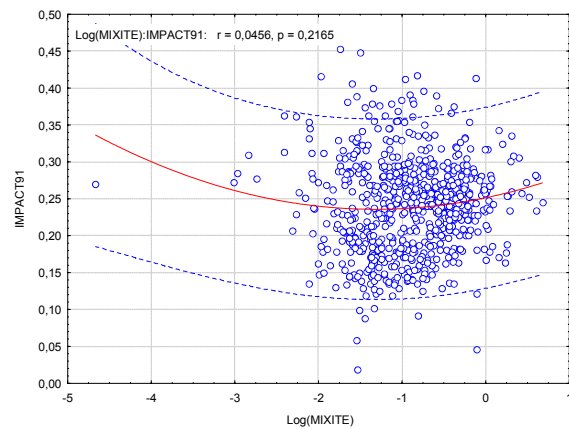
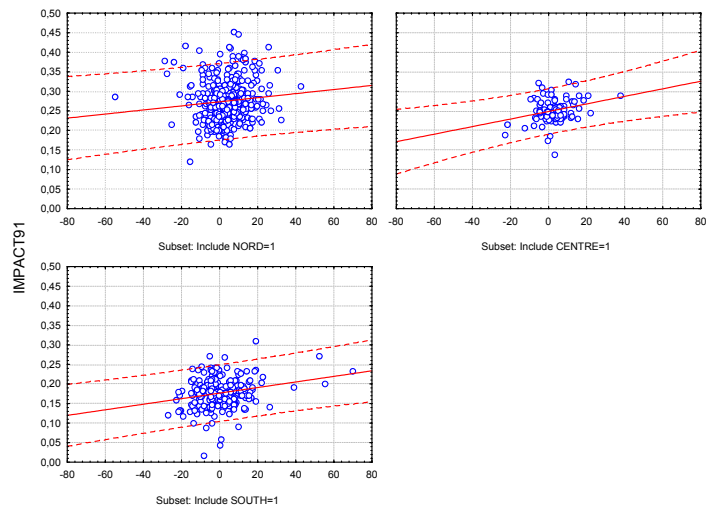
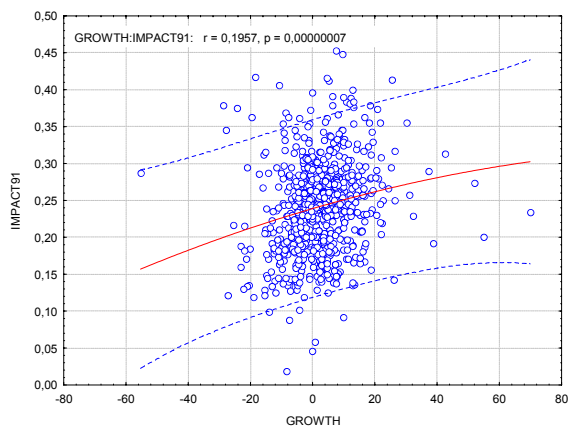


Figure 4a: scatter plots of ‘spatial’ explanatory variables, with polynomial and linear fitting and regression bands at 95 percent prediction level.

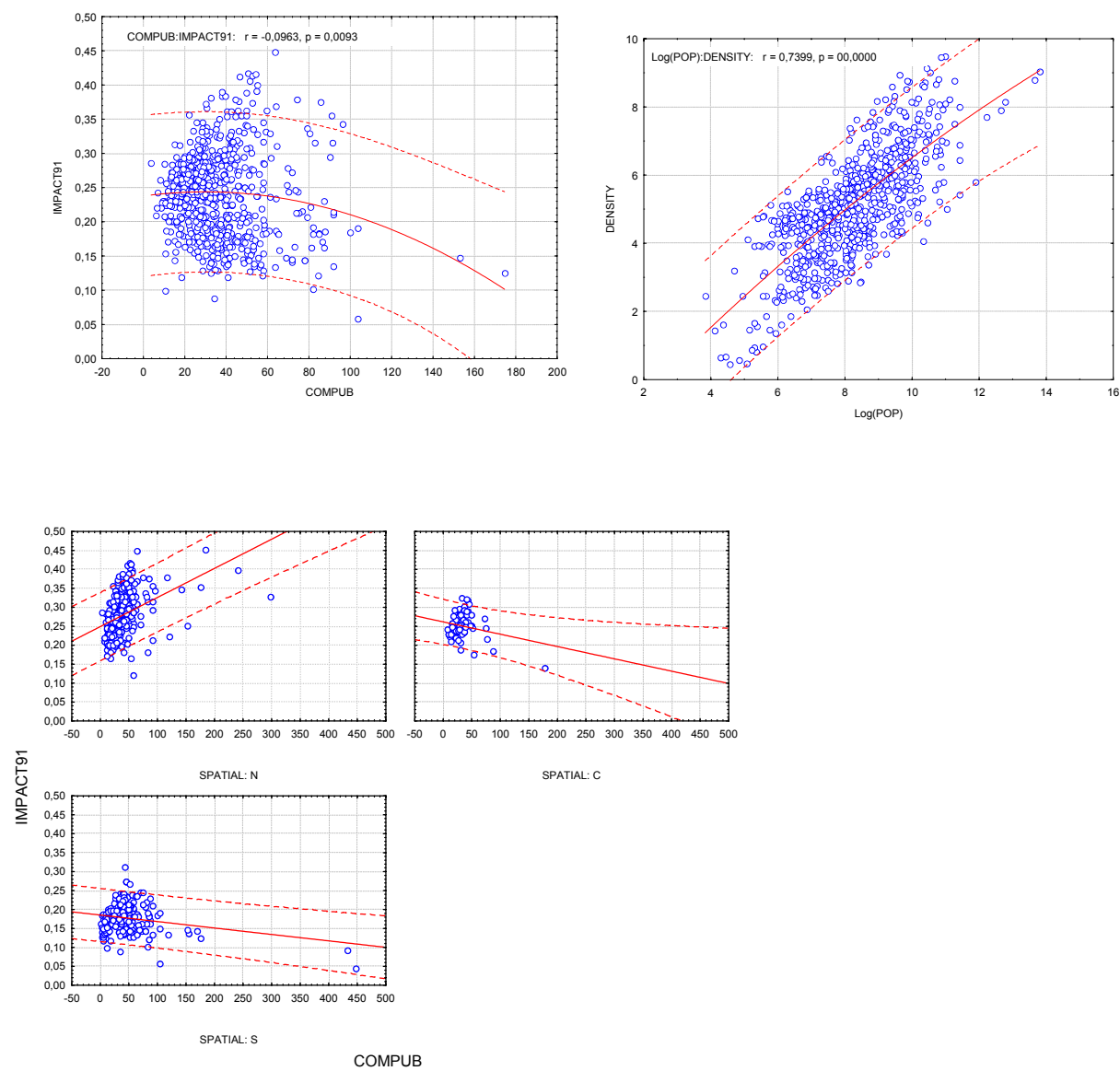
Figure 4b: Scatter plots of ‘socio-economic’ explanatory variables with polynomial and linear fitting and regression bands at 95 percent prediction level.

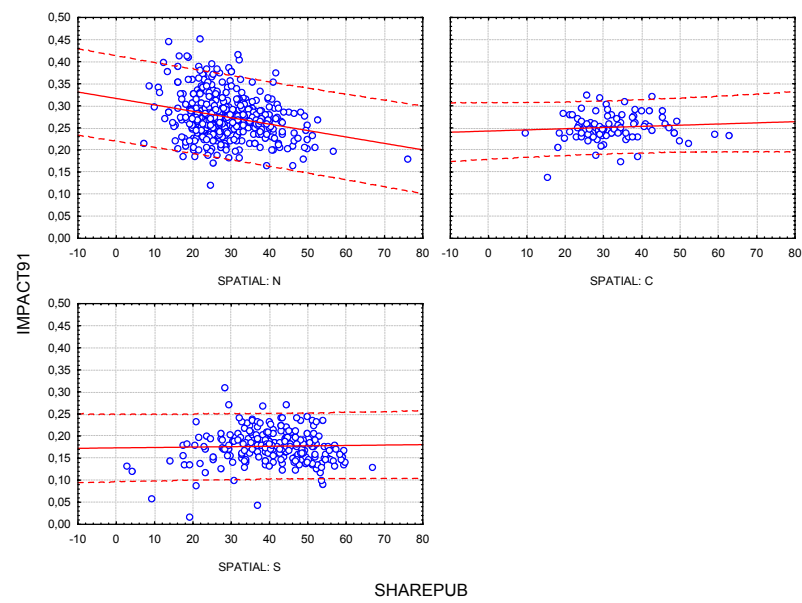
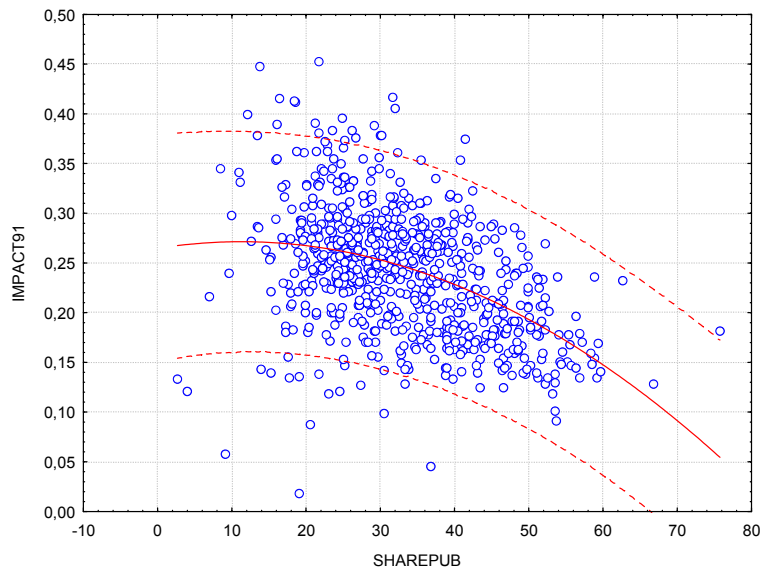


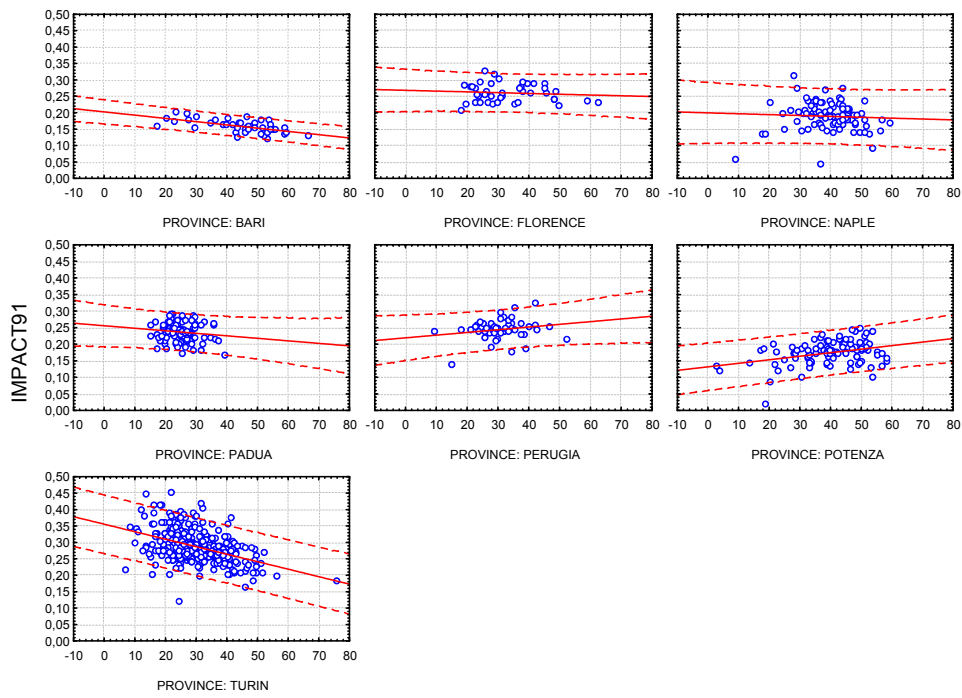


SELFCONT

Figure 4c: Scatter plots of ‘mobility’ variables, referring to 1991, with polynomial fitting and regression bands at the 95 percent prediction level.







SHAREPUB

2.1.4 Multiple Regression Variants and Estimation Results

The initial step of our analysis is to assess the average effect of explanatory variables, irrespectively of potential heterogeneities across different urban areas. We start therefore running multivariate regressions using pooled data. Preliminarily to this, we check for multicollinearity among independent variables and find no significant redundancy among them.

In the attempt to control for geographical differences, the model include the distance from the chief town of the related urban area (DISTANCE), and its rural ratio (RURAL). Among the number of socio-economic factors that might have a role in determining the degree of mobility intensity we focus on the dynamic of urban growth (GROWTH) and the residential versus productive vocation (log MIXITE) of a given settlement. We use the density of the urban development (DENSITY) as a proxy of sprawling behaviour¹². The model also includes a variable that estimates to which degree urban mobility is (at commune level) contained within the city borders or, instead, it spreads towards outside of the city (SELFCONT). We can interpret this as the capacity of a given urban area to contain mobility within its borders, a sort of mobility self-containment capacity, which is expected to be positively related to its productive attitude. In fact, to some extent, the higher is the productive attitude of an urban settlement, the higher its capacity to contain commuting within its borders¹³. Coming back to our main line of reasoning, we expect SELFCONT to be negatively correlated to the level of mobility impact for two reasons: on one side, the average trip times increase whenever moving direction outside the city; second, commuters moving out of their city usually prefer less environmental friendly travel means, especially their own car. We have a confirmation of this in Table 9, which reports the results of a comparison between the mobility impact indexes calculated, on one side, considering both commuters travelling within the town and those going out of it (sort of gross mobility) and, on the other side, indexes calculated considering only the net movements outside of the town. As expected, the intensity of the mobility impact is higher whenever considering the net movements towards outside of the city, up to the 51.3 percent for Potenza.

¹² We are aware of the limits of such procedure, whereas previous researches have proposed other, more accurate, indicators of urban sprawl (for a discussion see Camagni et al. 2002a). To have a better understanding of the spatial distribution of urban settlement within a given area and about their sprawling attitude, we are at the moment working on the development of graphical indicators of sprawl, based on the methodology proposed by Salvetti (1982).

¹³ A regression model of SELFCONT shows that the coefficient of MIXITE is positive and strongly statistically significant for all the cities of concern, with the exception of Potenza and Turin. This suggests that, *ceteris paribus*, residential cities can contribute to generate traffic and congestion more than urban areas with a higher level of 'functional mix'.

Besides, an important research issue here is to understand which role accessibility and efficiency of public transport can have in curbing the proliferation of urban traffic and congestion. On this perspective we expect that, as the overall competitiveness of public transport increases, commuters' preferences will move towards public transport means contributing to reduce traffic congestion and the intensity of mobility impact. To capture these dimensions we estimate the accessibility (market share) and the efficiency of public transport calculated as, respectively, the percentage of all trips made with public vehicles (SHAREPUB), and the ratio between the average trip times taken with private vehicles over the average times taken travelling with public ones (COMPUB).

We begin analysing the pooled data sample with a simple specification in which the dependent variable IMPACT91 is modelled as a linear additive function of the usual constant term, the spatial variables (DISTANCE, DENSITY, RURAL), the log of MIXITE, GROWTH, the variables controlling for the direction of urban mobility (SELFCONT), and three dummies controlling for the geographical position of the urban areas (NORTH and SOUTH) and whether they are metropolitan or polycentric ones (METRO). In Table 7 Model A shows that results are consistent with the outcomes of the univariate analyses. All coefficients have the expected sign and are highly statistically significant. Interestingly, SELFCONT contributes to reduce the mobility impact. We use F-test to assess how much heterogeneity among provinces need to be taken into account using a weighted least squares (WLS) estimator. The pooled regression model can be affected by heteroscedasticity because mobility impacts refers to different provinces with differing numbers of observations (i.e., different number of communes in each province, see Figure 1). We therefore use the number of observations of the underlying province as a proxy to account for the differing sample sizes available for each of the seven urban areas (see also Dalhuisen et al., 2003). The sample size of the different provinces ranges between 42 and 316 observations. Table 7 shows that OLS and WLS models provide significant and robust results consistent with our a priori expectations. Finally, Model C includes the variable measuring the quote of trips with public vehicles (SHAREPUB) and a proxy for the efficiency of private versus public transport (COMPUB). The model has a slightly higher explanatory power and it shows that both regressors are negatively and significantly correlated with the impact of urban mobility. Nevertheless, given the type of data available for the computation of the mobility index, which do not link trip duration with trip length, we are aware that these results might be biased by such underlying omission. The WLS model is omitted as it does not improve the performance of the analysis.

Table 7: Least squares regression analysis of the Mobility Impact index 1991 using pooled data.

	OLS Model A	WLS Model B	OLS Model C
Dependent variable:	IMPACT91	IMPACT91	IMPACT91
Independent variables:			
Intercept β	0.31*** (0.01)	0.29*** (0.68 ⁻⁰²)	0.33*** (0.89 ⁻⁰²)
DISTANCE	-0.43 ⁻⁰³ *** (0.66 ⁻⁰⁴)	-0.31 ⁻⁰³ *** (0.58 ⁻⁰⁴)	-0.44 ⁻⁰³ *** (0.65 ⁻⁰⁴)
DENSITY	-0.39 ⁻⁰⁵ ** (0.13 ⁻⁰⁵)-	-0.21 ⁻⁰⁵ * (0.11 ⁻⁰⁵)-	-0.40 ⁻⁰⁵ *** (0.13 ⁻⁰⁵)-
RURAL	-0.51 ⁻⁰³ *** (0.65 ⁻⁰⁴)	-0.48 ⁻⁰³ *** (0.60 ⁻⁰⁴)	-0.46 ⁻⁰³ *** (0.64 ⁻⁰⁴)
GROWTH	0.34 ⁻⁰³ ** (0.15 ⁻⁰³)	0.45 ⁻⁰³ ** (0.15 ⁻⁰³)	0.23 ⁻⁰³ *** (0.15 ⁻⁰³)
Log(MIXITE)	-0.011*** (0.002)	-0.011*** (0.002)	-0.010*** (0.002)
SELFCONT	-0.07*** (0.01)	-0.03*** (0.01)	-0.08*** (0.01)
METRO	0.01*** (0.3 ⁻⁰²)	0.01*** (0.3 ⁻⁰²)	0.01*** (0.3 ⁻⁰²)
NORTH	0.01** (0.44 ⁻⁰²⁴)	0.01** (0.33 ⁻⁰²⁴)	0.01** (0.43 ⁻⁰²⁴)
SOUTH	-0.07*** (0.52 ⁻⁰²)	-0.08*** (0.37 ⁻⁰²)	-0.07*** (0.53 ⁻⁰²)
SHAREPUBB	--	--	-0.65 ⁻⁰³ *** (0.15 ⁻⁰³)
COMPUBB	--	--	-0.93 ⁻⁰⁴ *** (0.43 ⁻³⁰)
Nobs	734	734	729
R ² -adj	0.64	0.65	0.66
F ^{test}	147.52***	154.34***	130.11***

Note: the weights are determined as the number of observations related to each of the seven underlying urban areas. Standard errors are given in parentheses, and significance is indicated by ***, ** and * for the 1, 5, and 10 percent level, respectively.

Previous results show that the proposed model performs well in explaining the factors driving heterogeneities in the impact that mobility has in different cities. Starting from this, we proceed running multiple regressions in cross-section in order to explore the existence of significant differences: i) across single urban areas; ii) across cities located in the north, centre or south of Italy and; iii) between metropolitan and polycentric urban areas. We use Wald-test on combined restrictions on model parameters and intercepts across such aggregate samples.

We start with the analysis of single urban areas. Table 8 reports the results of reduced and full specification OLS and WLS models (A, B, C). Similarly to the pooled model, the dependent variable IMPACT91 is modelled as a linear additive function of spatial, structural and mobility variables, with intercepts specific to each province. Overall, the results presented in Table 8 confirm the outcomes of the pooled models (Table 7), even though the significance of coefficients is reduced due to the limited number of observations available for sub-sample based on provinces. The F-test results point to preference for the weighted over the un-weighted model. A Wald-test on combined restrictions on the parameters across the different provinces, resulting in

seven aggregate samples, shows that the restrictions can be rejected and, therefore, that parameters are statistically different for cities belonging to diverse provinces (urban areas). As well, intercepts province specific are also statistically unequal.

In particular, major variations relate to the effects that the self-containment capacity and the quote of agricultural land have in explaining the IMPACT91 variance in different provinces. For such parameters, in fact, coefficients get either positive and negative sign. For instance, for SELFCONT, Naples and Turin have negative and significant coefficients whereas, instead, Perugia, Potenza, Florence and Bari have positive and highly significant coefficients in contrast with our expectation. Another contradictory result is that the quote of agricultural land favours higher mobility impact in Naples. Differently from the pooled model, the coefficient of SHAREPUB takes on negative and significant values only for the province of Florence and Turin. For Perugia and Potenza, the overall effect of higher rates of commuters travelling with public transport contributes to increase the intensity of the impact of mobility, probably due to longer average trip duration.

The main outcomes from these models can be summarised as follows (Table 8). The coefficients of the variable measuring the distance of a given town from the chief city (DISTANCE) are all negative and small in terms of absolute values. For the urban areas of Naples, Padua, Perugia, Potenza and Turin, coefficients are statistically significant and they remain stable across the two models. This suggests that going towards the most external part of the province, municipalities become more autonomous and they behave as sort of self-contained 'district' that contribute less to urban traffic. An inverse relationship is found between IMPACT91 and the gross population density (DENSITY). Coefficients are small in terms of absolute values and they are statistically different from zero for Florence and Turin.

An inverse relationship also exists with the variable RURAL, but for the case of Naples. Coefficients are statistically significant for Naples, Perugia, Potenza and Turin, though they are small in absolute values. We can interpret this as an effect of the smaller demand of mobility in areas with higher agricultural land rates. The log MIXITE variable captures the effect of the functional mix of the city on the intensity of the urban mobility impact. In our models, coefficients take on negative values but insignificant values for Bari, Florence, Naples, Padua, Perugia, Potenza, Turin. GROWTH, whenever significant, is positively related to the mobility impact.

It is however difficult to interpret results on the basis of single urban areas. We move, therefore, to a broader level of analysis and we run cross-section analysis on the basis of the geographical location and the level of polycentrism of urban areas (Table 10, Table 11), using the reduced and usual full model specification.

In Table 10 we can observe that the reduced and the full model on geographic location perform well in terms of explanatory power and significance of coefficients. Wald-test on combined restrictions on the parameters across North, Centre and South aggregate samples shows that null hypothesis of equality of regressors and intercepts coefficients across the three sub-samples can be rejected. In this case, the WLS model is not to be preferred to the OLS one and it is omitted in the table. We can argue from these results that the usual specifications can explain the variation in the intensity of the mobility impact at a broader spatial level than the local one. In fact, whenever significant, regressors take on the expected sign for each of the three sub samples, with the sole exception of the SELFCONT variable. SELFCONT coefficients are significant and negative for northern and southern cities, while the coefficient for central cities is positive. Regarding the effect of the rate of trips with public means, the coefficient is negative and significant only for Northern cities, according to the results of the univariate analysis.

Table 11 reports results obtained with aggregations on the basis of the level of polycentrism. Once more, Wald-test on combined restrictions on the parameters across polycentric and metropolitan aggregate cities samples shows that null hypothesis of equality of regressors and intercepts coefficients can be rejected. The WLS model is not to be preferred to the OLS one and it is omitted. Similarly to before, whenever significant, regressors take on the expected sign for each sub sample. There are however some differences in the elasticity of some explanatory variables. In particular, the effect of functional mix, growth rate and density is stronger for towns and cities belonging to a polycentric urban agglomeration whereas, instead, the effect of DISTANCE and RURAL is stronger for metropolitan ones.

Table 8: Least squares regression analyses of the mobility impact index 1991.

	Model A OLS	Model B WLS	Model C WLS
<i>INDMOB91</i>			
β_{Bari}	0.08 (0.06)	0.08*** (0.03)	0.10** (0.04)
$\beta_{Florence}$	0.27*** (0.05)	0.27*** (0.02)	0.30*** (0.03)
β_{Naples}	0.25*** (0.02)	0.25*** (0.01)	0.24*** (0.02)
β_{Padua}	0.21*** (0.04)	0.21*** (0.03)	0.18*** (0.03)
$\beta_{Perugia}$	0.26*** (0.04)	0.26*** (0.02)	0.23*** (0.02)
$\beta_{Potenza}$	0.18*** (0.03)	0.18*** (0.02)	0.15*** (0.02)
β_{Turin}	0.38*** (0.01)	0.38*** (0.01)	0.41*** (0.01)
DISTANCE			
Bari	0.10 ⁻⁰³ (0.32 ⁻⁰³)	0.10 ⁻⁰³ (0.16 ⁻⁰³)	0.12 ⁻⁰³ (0.16 ⁻⁰³)
Florence	-0.65 ⁻⁰³ (0.53 ⁻⁰³)	-0.65 ⁻⁰³ (0.27 ⁻⁰³)	-0.56 ⁻⁰³ (0.52 ⁻⁰³)
Naples	-0.10 ⁻⁰² *** (0.41 ⁻⁰³)	-0.10 ⁻⁰² *** (0.30 ⁻⁰³)	-0.11 ⁻⁰² ** (0.31 ⁻⁰³)
Padua	-0.10 ⁻⁰² *** (0.41 ⁻⁰³)	-0.11 ⁻⁰² ** (0.33 ⁻⁰³)	-0.11 ⁻⁰² *** (0.32 ⁻⁰³)
Perugia	-0.42 ⁻⁰³ (0.29 ⁻⁰³)	-0.42 ⁻⁰³ *** (0.16 ⁻⁰³)	-0.58 ⁻⁰³ *** (0.17 ⁻⁰³)
Potenza	-0.18 ⁻⁰³ * (0.96 ⁻⁰⁴)	-0.18 ⁻⁰³ *** (0.75 ⁻⁰⁴)	-0.14 ⁻⁰³ ** (0.73 ⁻⁰⁴)
Turin	-0.96 ⁻⁰³ *** (0.12 ⁻⁰³)	-0.95 ⁻⁰³ *** (0.17 ⁻⁰³)	-0.78 ⁻⁰³ *** (0.17 ⁻⁰³)
DENSITY			

	Model A OLS	Model B WLS	Model C WLS
Bari	0.68 ⁻⁰⁵ (0.16 ⁻⁰⁴)	0.68 ⁻⁰⁵ (0.83 ⁻⁰⁵)	0.48 ⁻⁰⁵ (0.81 ⁻⁰⁵)
Florence	-0.20 ⁻⁰⁴ (0.15 ⁻⁰⁴)	-0.21 ^{-04***} (0.76 ⁻⁰⁵)	-0.24 ^{-04***} (0.76 ⁻⁰⁵)
Naples	0.97 ⁻⁰⁶ (0.19 ⁻⁰⁵)	0.97 ⁻⁰⁶ (0.14 ⁻⁰⁵)	0.77 ⁻⁰⁶ (0.14 ⁻⁰⁵)
Padua	-0.17 ⁻⁰⁴ (0.16 ⁻⁰⁴)	-0.17 ⁻⁰⁴ (0.12 ⁻⁰⁴)	-0.16 ⁻⁰⁴ (0.14 ⁻⁰⁴)
Perugia	-0.75 ⁻⁰⁵ (0.66 ⁻⁰⁴)	-0.75 ⁻⁰⁵ (-0.38 ⁻⁰⁴)	-0.47 ⁻⁰⁵ (-0.37 ⁻⁰⁴)
Potenza	-0.19 ⁻⁰⁴ (0.11 ⁻⁰³)	-0.19 ⁻⁰⁴ (0.93 ⁻⁰⁴)	-0.21 ⁻⁰⁴ (0.90 ⁻⁰⁵)
Turin	-0.17 ^{-04***} (0.43 ⁻⁰⁵)	-0.17 ^{-04***} (0.59 ⁻⁰⁵)	-0.15 ^{-04**} (0.58 ⁻⁰⁵)
RURAL			
Bari	0.31 ⁻⁰³ (0.53 ⁻⁰³)	0.31 ⁻⁰³ (0.28 ⁻⁰³)	0.32 ⁻⁰³ (0.27 ⁻⁰³)
Florence	-0.23 ⁻⁰⁴ (0.41 ⁻⁰³)	-0.23 ⁻⁰⁴ (0.20 ⁻⁰³)	-0.17 ⁻⁰³ (0.21 ⁻⁰³)
Naples	0.37 ^{-03*} (0.19 ⁻⁰³)	0.37 ^{-03**} (0.14 ⁻⁰³)	0.39 ^{-03***} (0.14 ⁻⁰³)
Padua	-0.15 ⁻⁰⁴ (0.28 ⁻⁰³)	-0.15 ⁻⁰⁴ (0.22 ⁻⁰³)	-0.11 ⁻⁰⁴ (0.22 ⁻⁰³)
Perugia	-0.33 ⁻⁰³ (0.33 ⁻⁰³)	-0.33 ^{-03*} (0.19 ⁻⁰³)	-0.20 ⁻⁰³ (0.20 ⁻⁰³)
Potenza	-0.46 ^{-03**} (0.21 ⁻⁰³)	-0.46 ^{-03**} (0.17 ⁻⁰³)	-0.41 ^{-03*} (0.16 ⁻⁰³)
Turin	-0.60 ^{-03***} (0.83 ⁻⁰⁴)	-0.60 ^{-03***} (0.12 ⁻⁰³)	-0.50 ^{-03***} (0.11 ⁻⁰³)
GROWTH			
Bari	0.45 ⁻⁰³ (0.69 ⁻⁰³)	0.45 ⁻⁰³ (0.36 ⁻⁰³)	0.35 ⁻⁰³ (0.35 ⁻⁰³)
Florence	0.70 ⁻⁰³ (0.63 ⁻⁰³)	0.70 ^{-03**} (0.31 ⁻⁰³)	0.69 ⁻⁰³ (0.30 ⁻⁰³)
Naples	0.21 ⁻⁰³ (0.31 ⁻⁰³)	0.21 ⁻⁰³ (0.23 ⁻⁰³)	0.26 ⁻⁰³ (0.23 ⁻⁰³)
Padua	-0.33 ⁻⁰³ (0.50 ⁻⁰³)	-0.33 ⁻⁰³ (0.40 ⁻⁰³)	-0.21 ⁻⁰³ (0.40 ⁻⁰³)
Perugia	-0.62 ⁻⁰³ (0.89 ⁻⁰³)	-0.62 ⁻⁰³ (0.51 ⁻⁰³)	-0.51 ⁻⁰³ (0.50 ⁻⁰³)
Potenza	0.61 ⁻⁰³ (0.60 ⁻⁰³)	0.61 ⁻⁰³ (0.47 ⁻⁰³)	0.60 ⁻⁰³ (0.45 ⁻⁰³)
Turin	0.60 ⁻⁰⁴ (0.21 ⁻⁰³)	0.59 ⁻⁰⁴ (0.29 ⁻⁰³)	0.35 ⁻⁰⁴ (0.20 ⁻⁰³)
Log MIXITE			
Bari	0.04 (0.04)	0.03* (0.02)	0.03 (0.02)
Florence	-0.01 (0.01)	-0.01 (0.01)	-0.02* (0.9 ⁻⁰²)
Naples	-0.31 ⁻⁰² (0.02)	-0.32 ⁻⁰² (0.02)	-0.30 ⁻⁰² (0.01)
Padua	-0.01 (0.8 ⁻⁰²)	-0.01* (0.7 ⁻⁰²)	-0.01 (0.7 ⁻⁰²)
Perugia	-0.02 (0.03)	-0.02 (0.08)	-0.02 (0.17)
Potenza	0.01 (0.02)	0.96 ⁻⁰² (0.02)	0.64 ⁻⁰² (0.01)
Turin	-0.68 ⁻⁰³ (0.8 ⁻⁰²)	-0.68 ⁻⁰³ (0.1 ⁻⁰²)	-0.26 ⁻⁰³ (0.11 ⁻⁰²)
SELFCONT			
Bari	0.07 (0.05)	0.07*** (0.03)	0.06 ** (0.03)
Florence	0.04 (0.06)	0.04 (0.03)	0.03 (0.03)
Naples	-0.15*** (0.02)	-0.15*** (0.02)	-0.14*** (0.02)
Padua	0.13*** (0.03)	0.13*** (0.03)	0.14*** (0.03)
Perugia	0.09** (0.04)	0.09*** (0.02)	0.08*** (0.02)
Potenza	0.12*** (0.04)	0.12*** (0.03)	0.11*** (0.03)
Turin	-0.08*** (0.01)	-0.08*** (0.02)	-0.08*** (0.02)
SHAREPUBB			
Bari			-0.42 ⁻⁰ (0.31 ⁻⁰³)
Florence			-0.54 ⁻⁰³ (0.32 ⁻⁰³)
Naples			0.30 ⁻⁰³ (0.32 ⁻⁰³)
Padua			0.67 ⁻⁰³ (0.61 ⁻⁰³)
Perugia			0.13 ^{-02**} (0.46 ⁻⁰³)
Potenza			0.75 ^{-03***} (0.23 ⁻⁰³)
Turin			-0.15 ^{-02***} (0.29 ⁻⁰³)
N° obs.	734	734	732
R ² adj	0.72	0.77	0.79
F ² test	39.21***	52.04***	49.72***
Wald-test on restrictions	p<0.00***	p<0.00***	p<0.00***

Note: the weights are determined as the number of observations related to each of the seven underlying urban areas. Standard errors are given in parentheses, and significance is indicated by ***, ** and * for the 1, 5, and 10 percent level, respectively.

Table 9: Descriptive statistics of the mobility impact index per metropolitan area.

	Mobility Impact Index										Increase rate (a-b)
	Mean		Median		Std. dev		Minimum		Maximum		
	a	b	a	b	a	b	a	b	a	b	
Naple	0.189	0.269	0.189	0.270	0.042	0.056	0.045	0.042	0.312	0.400	29.7%
Turin	0.287	0.362	0.287	0.350	0.049	0.064	0.121	0.219	0.453	0.789	20.6%
Bari	0.159	0.296	0.159	0.294	0.019	0.036	0.119	0.245	0.201	0.415	46.5%
Florence	0.260	0.371	0.260	0.354	0.028	0.056	0.206	0.294	0.326	0.556	29.8%
Padua	0.237	0.340	0.237	0.337	0.028	0.032	0.167	0.284	0.289	0.427	30.4%
Perugia	0.244	0.370	0.244	0.361	0.030	0.050	0.139	0.293	0.323	0.544	33.9%
Potenza	0.174	0.357	0.174	0.350	0.036	0.082	0.019	0.048	0.246	0.577	51.3%

Note:

- (a) Mobility impact index calculated considering both commuters going outside and moving within a given commune:
(b) Mobility impact index calculated considering only those commuters going outside a given commune.

Table 10: Cross-section analysis of the Mobility Impact Index 1991 on the basis of the geographical position of towns and cities.

	OLS (Model A)	OLS (Model B)
Dependent variable:	IMPACT91	IMPACT91
Independent variables:		
Intercept β_{North}	0.37*** (0.01)	0.39*** (0.94 ⁻⁰²)
β_{Centre}	0.25*** (0.02)	0.25*** (0.03)
β_{South}	0.21*** (0.01)	0.20*** (0.02)
DISTANCE		
North	-0.88 ⁻⁰³ *** (0.12 ⁻⁰³)	-0.74 ⁻⁰³ *** (0.12 ⁻⁰³)
Centre	-0.43 ⁻⁰³ * (0.25 ⁻⁰³)	-0.44 ⁻⁰³ * (0.25 ⁻⁰³)
South	-0.24 ⁻⁰³ *** (0.83 ⁻³⁰)	-0.23 ⁻⁰³ *** (0.82 ⁻³⁰)
DENSITY		
North	-0.18 ⁻⁰⁴ *** (0.43 ⁻⁰⁵)	-0.15 ⁻⁰⁴ *** (0.43 ⁻⁰⁵)
Centre	-0.17 ⁻⁰⁴ * (0.11 ⁻⁰⁴)	-0.16 ⁻⁰⁴ (0.11 ⁻⁰⁴)
South	0.16 ⁻⁰⁵ (0.15 ⁻⁰⁵)	0.16 ⁻⁰⁵ (0.15 ⁻⁰⁵)
RURAL		
North	-0.72 ⁻⁰³ *** (0.79 ⁻⁰⁴)	-0.68 ⁻⁰³ *** (0.78 ⁻⁰⁴)
Centre	-0.30 ⁻⁰³ (0.23 ⁻⁰³)	-0.27 ⁻⁰³ (0.25 ⁻⁰³)
South	-0.18 ⁻⁰³ (0.11 ⁻⁰³)	-0.19 ⁻⁰³ * (0.11 ⁻⁰³)
GROWTH		
North	0.47 ⁻⁰⁴ (0.20 ⁻⁰³)	0.67 ⁻⁰⁵ (0.20 ⁻⁰³)
Centre	0.21 ⁻⁰³ (0.52 ⁻⁰³)	0.19 ⁻⁰³ (0.51 ⁻⁰³)
South	0.46 ⁻⁰³ * (0.24 ⁻⁰³)	0.48 ⁻⁰³ ** (0.23 ⁻⁰³)
Log(MIXITE)		
North	-0.01*** (0.24 ⁻⁰²)	-0.73 ⁻⁰² *** (0.24 ⁻⁰²)
Centre	-0.01 (0.01)	-0.01 (0.01)
South	-0.92 ⁻⁰² * (0.54 ⁻⁰²)	-0.94 ⁻⁰² * (0.53 ⁻⁰²)
SELFCONT		
North	-0.09*** (0.11 ⁻⁰³)	-0.10*** (0.01)
Centre	0.07** (0.03)	0.07** (0.03)
South	-0.07*** (0.02)	-0.07*** (0.02)
SHAREPUBB		
North		-0.98 ⁻⁰³ *** (0.21 ⁻⁰³)
Centre		0.12 ⁻⁰³ (0.49 ⁻⁰³)
South		0.17 ⁻⁰³ (0.22 ⁻⁰³)
Nobs	734	732
R ² -adjusted	0.66	0.68
F ² test	73.84***	68.16***
Wald-test on restrictions	197.74***	572.49***

Note: the weights are determined as the number of observations related to each of the seven underlying urban areas. Standard errors are given in parentheses, and significance is indicated by ***, ** and * for the 1, 5, and 10 percent level, respectively.

Table 11: Cross-section analysis of the Mobility Impact Index 1991 on the basis of the level of polycentrism of towns and cities.

	OLS (Model A)	OLS (Model B)
Dependent variable:	IMPACT91	IMPACT91
Independent variables:		
Intercept β_{Polyc}	0.22*** (0.02)	0.22*** (0.21)
β_{Metro}	0.39*** (0.88 ⁻⁰²)	0.43*** (0.01)
DISTANCE		
Polycentric	-0.33 ⁻⁰³ *** (0.11 ⁻⁰³)	-0.33 ⁻⁰³ *** (0.10 ⁻⁰³)
Metropolitan	-0.79 ⁻⁰³ *** (0.13 ⁻⁰³)	-0.45 ⁻⁰³ *** (0.12 ⁻⁰³)
DENSITY		
Polycentric	-0.23 ⁻⁰⁴ (0.15 ⁻⁰⁴)	-0.23 ⁻⁰⁴ (0.13 ⁻⁰³)
Metropolitan	-0.18 ⁻⁰⁴ *** (0.15 ⁻⁰⁵)	-0.13 ⁻⁰⁴ *** (0.15 ⁻⁰³)
RURAL		
Polycentric	-0.56 ⁻⁰³ *** (0.18 ⁻⁰³)	-0.56 ⁻⁰³ *** (0.17 ⁻⁰³)
Metropolitan	-0.97 ⁻⁰³ *** (0.85 ⁻⁰⁴)	-0.70 ⁻⁰³ *** (0.81 ⁻⁰⁴)
GROWTH		
Polycentric	0.77 ⁻⁰³ * (0.43 ⁻⁰³)	0.77 ⁻⁰³ * (0.39 ⁻⁰³)
Metropolitan	0.51 ⁻⁰⁴ (0.21 ⁻⁰²)	0.14 ⁻⁰⁵ (0.19 ⁻⁰³)
Log(MIXITE)		
Polycentric	0.99 ⁻⁰³ (0.72 ⁻⁰²)	0.99 ⁻⁰³ (0.66 ⁻⁰²)
Metropolitan	0.2 ⁻⁰³ (0.29 ⁻⁰²)	0.53 ⁻⁰³ (0.26 ⁻⁰²)
SELFCONT		
Polycentric	-0.13*** (0.23)	0.13*** (0.02)
Metropolitan	-0.14*** (0.13)	-0.13*** (0.01)
SHAREPUBB		
Polycentric		-0.22 ⁻⁰² *** (0.02)
Metropolitan		0.57 ⁻⁰⁵ (0.30)
Nobs	734	732
R ² -adj	0.45	0.55
F ² test	47.69***	60.61***
Wald-test on restrictions	151.97***	169.27***

Note: the weights are determined as the number of observations related to each of the seven underlying urban areas. Standard errors are given in parentheses, and significance is indicated by ***, ** and * for the 1, 5, and 10 percent level, respectively.

2.1.5 A conceptual interpretation of mobility impact

The conceptual model

Moving further from the results presented in the previous paragraph, we try now to enrich our analysis envisaging a conceptual causal chain in the explanation of the mobility impact intensity, in which the mobility impact is the results of the influence of three main territorial dimensions: structural economic and social, as shown in Figure 5. In our model, the causal chain origins from the structural features of the urban settlement that we interpret as drivers of all other elements in the conceptual chain. In particular, we focus on the self-containment capacity of a given city, as a result of urban form and urban functional mix. The structural dimension of our conceptual model, here represented by the self-containment capacity, is therefore supposed to influence the intensity of the mobility impact through the economic and

the social dimension. The economic element is represented by the competitiveness of public vs private transport (in terms of time efficiency), which is a results of the structural features of the urban settlement (e.g. urban density, functional diversification, etc). The social element is represented by the modal choice of the city inhabitants, depending on the competitiveness of the public vs private transport that, on its turn, is related to the urban settlement features.

Stigmatising the previous discussion, we have that settlement of relatively compact structure and good functional mix will be characterised by higher self-containment capacity. This will generate more favourable conditions for public transport competitiveness (in terms of journey-to-work time) that, on its turn, will move people preferences towards public travel means and, consequently, lower impacts of urban mobility.

From this conceptual interpretation we try now to move to the econometric analysis to find some empirical evidence of it. Before presenting our results, however, it is necessary to notice that our causal interpretation of the mobility index derives from a priori knowledge on the phenomenon and it can not be derived straight from the statistical estimation process.

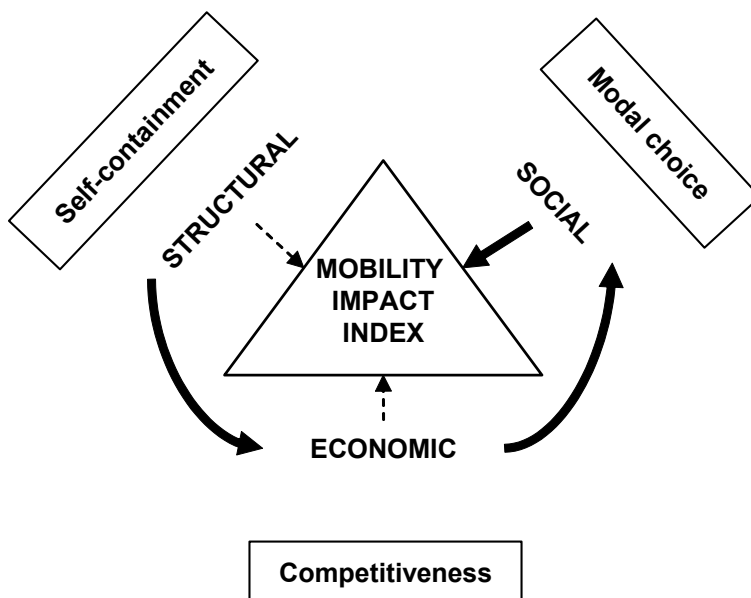


Figure 5: Causal chains in the explanation of mobility impact.

The Causal Path Analysis

In order to test the hypothesis on the causal chain in the explanation of mobility impact, we employ a methodology based on Causal Path Analysis (CPA) (an in-depth description see e.g. Bollen, 1989). This type of analysis formulates the model as a path diagram, in which arrows connecting variables define the structure of the conceptual framework and allow the estimation of reaction parameters, i.e., essentially the regression coefficients. The arrow diagram of Figure 6 contains the structure of the causal path that we want to test, which comes from the conceptual model presented in Figure 5. On the right hand side we have the *endogenous* variable (dependent), i.e. the variable that in the end has to be explained by all other variables in the model. The remaining variables in the scheme are *exogenous* and *intermediate* variables, where the former are independent (in the sense that their variation is taken for granted in the model), while the latter can be influenced by variation in the exogenous variables. Among various statistical methods, we use the Generalised Least-Square (GLS) method to run the path analysis. GLS allows us to construct a model of linear equations, in which a given variable can behave both as independent variable (in one equation) and as dependent variable in a subsequent equation. We can therefore estimate regression coefficients in a simultaneous regression model. Under the assumption that each variable has been standardised to unit variance and mean zero, the value assumed by individual parameters represents the order of magnitude of each independent variable in explaining the following dependent variable. The statistical significance of each parameter is given by the values of T-statistics run in parallel to the coefficient estimation analysis.

In the framework of our analysis three latent variables are chosen, one for each territorial dimension included in the conceptual model, plus three exogenous variables that capture the structural pattern of any given city. MIXITE, DENSITY and RURAL are chosen as exogenous variables and they describe, respectively, the functional mix and the urban sprawl attitude of a given urban area. SELFCONT is chosen to represent the structural dimension; COMPUBB is the economic element of the model, while SHAREPUB estimates individual preferences for public travel means, i.e. the social element. Impact of urban mobility is estimated by our Mobility Impact Index. The causal direction of the chain is given by arrows in

Figure 7. Results are presented in

Figure 7 with coefficients and T-values in brackets. From this it is easy to see that our conceptual model appears to be confirmed. All parameters are highly statistically significant and have the expected sign. The level of self-containment depends on some structural elements here represented by, in particular, residential density, functional mix and incidence of rural land. In this respect it is interesting to notice that, as the productive vocation of the settlement increases (MIXITE), the level of mobility self-containment increases too. The same goes for urban density and ratio of agricultural land. From the results presented in

Figure 7, we also have a confirmation of the causal link between self-containment and competitiveness of public transport. The SELFCONT coefficient is positive and highly statistically significant, meaning that as self-containment capacity goes up,

competitiveness of public transport increases, as expected. Besides, the relationship between modal choice (SHAREPUBB) and competitiveness of public transport (COMPUBB) is also confirmed to be positive and highly statistically significant. As expected, a greater efficiency of public transport contributes to move individual choices towards public travel means and, therefore, to reduce the overall impact of urban mobility. The last link of our chain is indeed negative meaning that, as expected, all else being the same, if individual preferences move towards public travel means, we can expect a reduction of urban mobility impact.

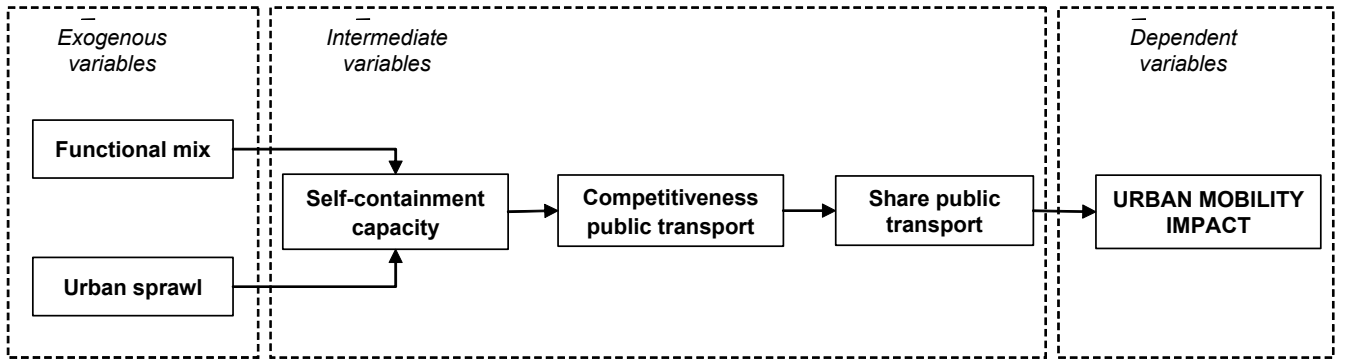


Figure 6: A general model for urban mobility impact estimates.

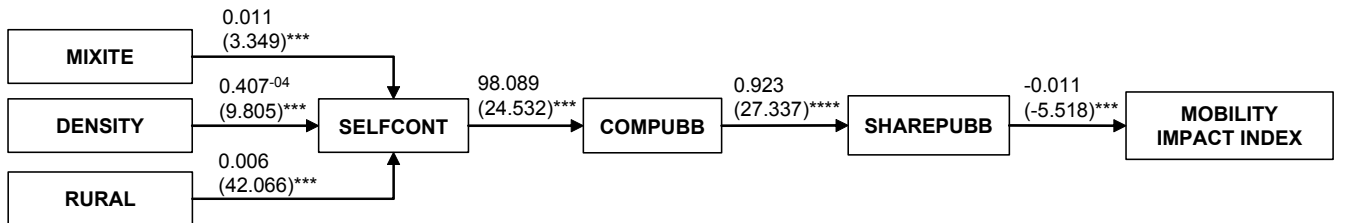


Figure 7: Estimated path analysis model for Italy. T-statistics are provided in brackets. Significance is indicated by ***, ** and * for the 1, 5, and 10 percent level, respectively.

2.2 Conclusions

In Europe, the debate on collective costs associated with sprawling urban patterns is recent and it advocates for empirical evidence of their dimensions as, so far, sound empirical and quantitative analysis is still rare. It is indeed a hard task to measure such externalities and, even more, to provide an econometric analysis of the link between the way in which an urban area develops and its effects in terms of collective costs. In this respect, we focus on urban mobility and provide a broad empirical analysis on both the dynamic of urban mobility during the decade 1981-1991 and the factors determining the intensity of mobility pressure in Italy.

We select seven Italian urban areas, located in the north, centre and south of Italy, and use journey-to-work data to compute a mobility impact index at commune level, for the years 1981 and 1991. The mobility index is based on a weight matrix that associates less environmental friendly mobility behaviours with higher impact scores (Camagni et al, 2002b).

A first result is that –as expected– during such decade, the impact of urban mobility has increased noticeably in the whole peninsula, up to the 37.3 percent. A regression model shows that the higher rate of use of private car is one of the main determinants of such an increase.

Subsequently, we describe our hypothesis as to the reasons to explain heterogeneities in intensity of mobility impact and use cross-section regression framework to test them empirically. Models refer to 1991 data and include variables controlling for structural and socio-economic features of the urban settlement, with a special focus on sprawling attitude and competitiveness and efficiency of public versus private transport. Among the structural factors, whenever statistically significant, urban density, functional mix (economic-residential balance) and rural ratio are negatively correlated to the mobility impact index, while demographic growth rate is positively correlated. Higher impacts are associated with diffused, sprawling development, residential specialisation and more recent urbanisation processes.

Finally, we try to enrich our analysis envisaging a conceptual causal chain in the explanation of the mobility impact intensity, which relies on three main components: structural, economic, and social. The three components are represented, respectively, by: self-containment capacity of a given urban area, competitiveness of public vs private transport (in terms of time efficiency), modal choice. In our conceptual model, structural factors are drivers of competitiveness of public transport, which, on its turns, influences peoples' preferences on alternative modal travel means. We test such causal relationship using CPA we find substantial confirmation of this, as all coefficients have the expected sign and they are highly statically significant. Results show that the level of self-containment depends on the structural form of urban development, and in particular on its residential density, functional mix and incidence of farmland. Results also show a positive correlation between the self-containment indicator and the public transport competitiveness; and between public transport competitiveness and travel means preferences. Finally, CPA shows a negative and statistically significant correlation between an increase in the use of public transport and the intensity of urban mobility.

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